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THE EVALUATION OF SMALL ARMS EFFECTIVENESS CRITERIA

VOLUME I

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INTREC, INC.
Santa Monica, California 90401

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SUMMARY

The purpose of this study is to convey general information about the various types of tests for small arms (especially tests of effectiveness, where problems are most likely to arise), and about the steps, methods, and equipment involved in conducting them. The study is also intended to characterize the state of U.S. testing facilities for small arms.

- The types of small arms tests and the administrative mechanisms for their conduct are described and analyzed.
- The basic components of small arms field experiments (operational testing) are described, and sources of information for planning and conducting them are identified. The application of these components to types of small arms tests other than field experiments is noted.
- To illustrate the use and application of the components, a major small arms field experiment is reviewed. It is the CDEC-SAWS test of small arms, conducted in 1965-1966 at the U.S. Army Combat Developments Command Experimentation Center, Fort Ord, California.
- The current U.S. facilities for conducting small arms field experiments are surveyed, new equipment identified, and both facilities and new equipment are evaluated for their utility.

Findings pertaining to the general administration of small arms testing include:

1. The terminology in current DOD directives and Army regulations concerned with testing confuses and obscures the types of small arms testing that need to be conducted, as well as the necessary adversary relationship between user and developer.

2. Currently prescribed small arms service tests are of limited utility. The first comes too early in the development of small arms to permit evaluation of their suitability for Army use. The second does not occur until after significant acceptance decisions have been made and is thus too late to affect decision-making.

3. The quality of user tests, particularly the more important field experiments, suffers severely under the constraint prohibiting the user from planning and conducting major user-oriented tests.

4. The lack of a procedure for effectiveness testing of small arms early in their development restricts the United States' ability to take full advantage of its small arms inventors and innovators.

With respect to the conduct of small arms field experiments (operational tests), the specific findings include:

1. The most appropriate organizational unit for operational testing that can be defined at this time is the rifle and machine gun squad.

2. Small arms target systems can be adequately described on the basis of analyses of infantry tactics and historical combat data.

3. Combat firing situations cannot be as well characterized. However, data presented in this report (which may be biased, being derived from combat photography) indicate a high incidence of fire in upright, as compared with prone, firing positions. They also indicate that first-round firing occurs very quickly.

4. Measures of effectiveness are best defined in terms of the specific objectives of each operational test. However, target hits as a function of time, near misses as a function of time, and the level at which these target effects can be sustained as a function of weight are always important measures.

5. The performance of test subjects is conditioned by their prior small arms experience. A firer's prior training on one weapon will require substantial retraining to achieve comparable performance on other weapons--particularly if there are substantial differences in the way the weapons are fired.

6. The small arms firing range complexes at CDEC-HLMR and Ft. Benning are not suitable for the conduct of field experiments. Extensive effort would be necessary to make them suitable.

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Chapter I

INTRODUCTION

PURPOSE

The absence of valid theory for predicting how changes in the design of small arms will influence their effectiveness makes it all the more important to devise and conduct valid tests of the effectiveness of small arms. Those responsible for guiding small arms testing need to determine what kind of test is appropriate for assessing various aspects of a weapon at various stages of its development, and they need to ensure, by choosing appropriate methods and equipment for conducting them, valid results from the tests.

Bearing those needs in mind, the purpose of this study is to convey general information about the various types of tests for small arms (especially tests of effectiveness, where most problems are likely to be encountered), and about the steps, methods, and equipment involved in conducting them. The study is also intended to characterize the state of U.S. testing facilities for small arms.

BACKGROUND

Small arms are the basic weapons of a nation's infantry squads and platoons, and the effectiveness of these units is a major determinant of a nation's military stature. Squads and platoons have the most direct contact with the enemy; they physically occupy contested terrain; and they suffer most of the casualties of modern warfare.

The effectiveness of infantry squads and platoons depends on their leadership, the support provided to them by other combat arms, on their morale, motivation, and state of training, and on the excellence of their primary weapons--small arms.

As small arms are carried by personnel in other kinds of military units, they link a nation's entire military force as well as the forces of allied nations using the same weapons. In that sense small arms are a symbol as well as a weapon, and choosing what small arms system to buy is a decision of national importance. The testing of small arms is, in turn, a key factor in that decision.

At first glance, the testing of small arms may not appear to present particular difficulties. The physical principles governing the design of most modern small arms have been in general use for several decades. Only evolutionary changes have occurred in weapon design since the invention of smokeless powder and efficient brass cartridges in the late nineteenth century and the operating mechanisms they made possible.* On close inspection, however, neither the design of small arms nor the evaluation of their utility in combat is as simple as might be supposed. The main reason is the complex nature of infantry combat.

This can be illustrated by reference to the weight of weapon systems. Infantry soldiers are severely constrained by weight, and extreme fatigue is associated with sustained combat. Thus, lighter weight is sought for small arms and their ammunition because it will tire the infantryman less or permit him to carry a more effective load. Lighter weight is usually achieved, however, only by accepting trade-offs against other characteristics such as penetration or range. The relative importance of these factors is impossible to quantify because it is a matter of judgment.

Good small arms gun and ammunition systems tend to be the result of a complex series of trade-offs based on the designer's skill in mechanical design and his understanding of infantry combat. Thus, during the last century small arms design has been dominated by a relatively few designers of extraordinary ability. As another consequence, the compromises that these designers build into their weapons (because of their different

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*Smokeless powder provided a propellant with a longer burning time, thus permitting the buildup of higher velocities in the barrel without unacceptable recoil. Brass cartridge cases provided an inexpensive means of sealing the chamber as each round was fired. The mechanisms of Maxim, Browning, and many others exploited the potentials of these inventions.

perceptions and evaluations of the trade-offs) often result in differences in weapon performance whose operational impact cannot be readily understood or predicted on the basis of technical performance characteristics alone. The fact that a weapon and its ammunition perform well with respect to these characteristics does not necessarily mean that they will be highly useful in combat. The performance of small arms in organizational and tactical contexts needs to be tested as well.

The performance of small arms tends to be assessed in two ways. The first, alluded to above, is by measuring a standard set of performance characteristics. These may be important to combat effectiveness but they do not completely characterize it. Examples of such performance characteristics are ballistic dispersion, penetration and damage of various materials as a function of range, recoil force, muzzle impulse, reliability, rate of fire, and system weight. The second way is by means of measures of effectiveness defined for specified operational environments. These measures are intended to reflect the composite effect of performance characteristics in complex combat situations. An example of such a measure is hits as a function of time on a target complex.

Two classes of tests stem from these two ways of assessing the performance of small arms. Assessment by performance characteristics usually results in "development" tests, and assessment by measures of effectiveness usually results in "user" tests. When user tests involve only rudimentary measures of effectiveness, as they often do, they differ little from development tests.

SCOPE

The study investigates all types of testing of rifles, automatic rifles, carbines, submachine guns, and light machine guns. Grenade launchers and 50-caliber machine guns are excluded. The explanations of the various kinds of tests stress general principles and the information needed to approach the design of a given test or to evaluate testing activities; they do not constitute detailed plans for particular tests.

METHOD

For each major type of test identified, the purpose, mode of conduct, agencies responsible, resources required, and official procedures are described. Significant changes since 1960 are noted.

To deepen and extend an understanding of the testing process, the major steps in the design, conduct, and analysis of small arms tests are examined. The field experiment or operational type of test is stressed because it includes most of the significant aspects of other effectiveness and engineering tests. To illustrate how these major elements fit together in the entire testing process, an actual field experiment, conducted in 1965-1966 at the U.S. Army Combat Development Experimentation Command--Small Arms Weapon Systems (CDEC-SAWS), is reviewed as a case study. The facilities in the United States for conducting small arms operational tests are examined. They include the small arms testing and training ranges and equipment available for upgrading these ranges or constructing new ones. Finally, conclusions are drawn regarding the qualities to be sought and pitfalls to be avoided in the design, conduct, and analysis of small arms tests.

The study is based on direct observation and analysis of test data rather than on secondary reports or reviews of the literature.

ORGANIZATION OF THE REPORT

This report proceeds as follows. Chapter II defines and describes the various types of small arms tests. Chapter III identifies the basic steps involved in designing, conducting, and analyzing field experiments. Chapter IV furnishes a case study of the procedures described in Chapter III by describing the CDEC-SAWS test. Chapter V examines how current small arms testing is constrained by the availability of firing ranges and equipment for simulating and controlling the testing environment and for measuring the test results. Chapter VI presents the findings and conclusions. Detailed technical data and references appear in the appendices.

Chapter II

SMALL ARMS TESTS

This chapter first defines the various types of small arms tests and briefly describes their purpose, procedures, and resources required. Then it discusses the regulations governing small arms testing and the agencies responsible for its various aspects. Finally, problems in the management of tests are identified.

TYPES OF TESTS

Engineering Design Tests

The engineering design test is conducted primarily to reveal to the weapon designer the mechanical and ballistic functioning of the weapon or ammunition. It normally includes some measurement of acceleration and velocity of key components, wear, erosion, chamber pressures, muzzle velocities, and projectile trajectories (for new rounds). A small number, perhaps one to three, early prototypes are fired by technicians in a laboratory. The test identifies problems for correction by the designer and may indicate how well the prototypes meet technical specifications or the designer's objectives. Engineering design tests are run on weapons that are developed both within the DOD and by private manufacturers. If the latter, the manufacturer conducts the test. Otherwise, and with all the tests described below, the government does the testing.

Engineering Tests

Engineering tests are conducted at the end of the development process to determine whether a weapon meets the technical specifications and whether it is safe for user testing.* A body of standard engineering

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*Recalling the distinction made in Chapter I between "development" and "user" tests, it should be noted that of the tests described in this chapter only engineering design and engineering tests are development tests. The rest are either user tests or fall in an intermediate category of interest to both user and developer. The issue is discussed in more detail on pp. II-8ff.

test procedures for small arms has been developed over the years; specifications are often written for performance as measured by such procedures. These tests generally include the measurement of ballistic dispersion, muzzle flash, and cook-off resistance and an assessment of the weapon's endurance and reliability under laboratory simulation of unlubricated conditions, extreme cold, dust, rain, and mud (see the example in Appendix C). Terminal ballistics tests against helmets, body armor, pine boards, and sandbags are also usually conducted if new or modified ammunition is to be used. Wound ballistics tests, if done, are conducted separately (see p. II-5). Expert firers do the firing, and three to ten preproduction-model weapons are used.

Service Tests

The purpose of service testing is to determine the suitability of a weapon, or modification of a weapon, for Army use. The findings weigh heavily in the decision to adopt or reject a weapon proposed for standardization (type classification). The tests are run with preproduction weapons. For minor weapon modifications, they consist of a simple test of functioning under field conditions. The service check test is an example.

The service check test is done to verify that weapon changes recommended by previous service tests have been carried out, or to establish that technical improvements, e.g., a redesigned extractor spring, have not impaired the weapon's suitability for Army use. It is the simplest type of service test and is usually assigned to a project officer (often an experienced infantry captain) at the service test agency. He designs the test, has it approved within the agency, conducts it, and reports the results. Extensive test designs and complex measurement criteria are avoided.

For a major new weapon, extensive firing tests are conducted. Currently, these tests use (1) a group of firers of varying skill drawn from the infantry school troop unit at Fort Benning, (2) target systems with pop-up and moving pop-up targets at distances unknown to the firer, and (3) a control weapon--usually the weapon the test weapon or modification

is replacing. Typically about 20-30 test subjects fire several hundred rounds each; about 10-15 preproduction-model weapons are used (plus several control weapons).

Before the late 1960s, the service testing of small arms tended to duplicate engineering tests (e.g., reliability in mud, rain, arctic cold, and absence of lubrication; cook-off resistance; known distance range scores) under more realistic but less controlled conditions. That was because, first, user requirements ("military characteristics," MCs) were usually expressed as performance rather than effectiveness characteristics. (The distinction is that the former may or may not bear on combat effectiveness while the latter are intended to express both the combat function needed and a level of performance for that function.) Second, service test agencies had little capability to conduct tests to measure effectiveness directly. Thus it was natural for MCs to be expressed mainly in engineering terms.

Though service testing is still dominated by the expression of user requirements in measures heavily weighted toward engineering performance, by the late 1960s it was realized that such technical measures did not constitute an adequate basis for evaluating "suitability" for Army use. This coincided with the acquisition of range equipment that was potentially better able to simulate and measure combat firing. As a result, small arms service tests have become increasingly differentiated from engineering tests.

Other non-engineering tests such as air dropping, handiness in confined spaces, and safety in the field are also included in a major service test. If the test includes assessment of wound ballistics, another agency besides the service test agency usually does it.

Special-environment tests may be included in a major service test because arctic, jungle, and desert conditions may severely impair the reliability and firing of weapons. These tests are usually short versions of a regular service test and are conducted at facilities in the Arctic or Panama. Their engineering test counterparts are conducted in climate-controlled test chambers.

Field Experiments (Operational Tests)

Field experiments or operational tests* measure the effectiveness of weapons in an organizational and tactical context and are intended to be rigorously scientific. Such tests require a major commitment of resources, including time; the decision to conduct a field experiment should not be taken lightly. Field experiments are appropriate when a new small arms development is likely to have a fundamental impact on weapons choice or tactics whose nature cannot be adequately predicted on the basis of combat experience or conventional service testing.

A key feature of a field experiment is the necessity of defining measures of effectiveness. Unlike engineering and service tests, in which performance specifications or military characteristics may suffice, the field experiment requires that measures of effectiveness be defined. Often, this is the most difficult conceptual problem in planning the experiment.

Field experiments require several scarce or unusual resources. The weapon and ammunition that are to be tested must be available in considerable quantities. The natural organization level for the operational testing of small arms is the infantry squad (see p. III-9). Since several squads must be tested for each candidate weapon (or weapon mix) to obtain a statistically valid sample, fairly large numbers of test weapons, amounts of test ammunition, and test subjects are needed. The test weapons and ammunition must be developed to the point where they are nearly as reliable and safe as operational weapons.

Another necessary resource is a team that can plan, conduct, and analyze an experiment that is both scientifically rigorous and militarily valid. This may be the scarcest resource of all. It is of paramount importance that the aspects of the combat environment chosen for field simulation are critical ones and that the differences observed in this environment are truly attributable to differences in the weapons rather

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*The two terms are synonymous. Current regulations tend to confuse operational tests with all user tests, whereas they are merely one kind of user-oriented test.

than to artifacts of the test situation such as training, learning, or uncontrolled environmental effects.

The last main class of resources needed is physical facilities for conducting the experiment. Instrumentation is needed that can simulate the combat environment, insure its reproducibility from trial to trial, and accurately record data. The development of such instrumentation may be required as part of the experimentation process. The instrumentation also needs to be installed on terrain appropriate to the respesentative small arms combat situations chosen for simulation; large areas are required for safety.

Perhaps the most striking feature of field experiments is their inclusiveness. Measurement of the technical characteristics of the test weapons (e.g., ballistic performance, reliability, and diagnosis of malfunctions) are all part of field experimentation. Because a careful attempt is made to simulate firefights realistically, combat use factors can be obtained for ammunition and spare parts that will be useful in later cost-effectiveness analyses. Thus, the elements of most other types of tests are inherent in field experimentation. (An exception is wound ballistics testing, described below.)

Troop Tests

The purpose of troop tests is to lower the risk of unexpected training and logistic problems when new weapons are distributed to troops. The testing is done by selected operational units, who use the weapons in a series of "normal" training and tactical exercises. The measurement criteria are usually subjective, and results rely heavily on the observer's judgment and experience. Such tests seldom produce quantitative findings, though they may uncover important problems in training and maintenance.

Wound Ballistics Tests

Wound ballistics tests are intended to measure the incapacitating effects of small arms projectiles on men. The information is needed for weapons and ammunition design and for effectiveness comparisons of

developed weapons. Because wound ballistics tests require special resources such as medical laboratories and doctors to make autopsies, they are conducted by an agency separate from those normally involved in small arms testing.*

Precise estimates of the effects of bullets on people are impossible to obtain because, except for historical data on combat wounds, information must be derived from firings against targets other than people. The usual experimental targets are animals and gelatin blocks. The wound tracks observed in animals have been extrapolated to the human body; bullet cavities in gelatin blocks have been similarly extrapolated. Nevertheless, the relationship of gelatin block cavities or animal wounds to human incapacitation is tenuous. In fact, the data from animal wounds and from combat experience conflict significantly with gelatin-block extrapolations.

Military Potential and Military Exploitation Tests

Military potential tests are conducted to evaluate U.S. weapons produced outside the DOD research and development system or to evaluate foreign weapons. Although it is usually unlikely that such weapons would be procured, the tests are intended to keep U.S. developers and users apprised of possibly useful systems and features. Exploitation tests are conducted with the equipment of potential enemies to determine how the equipment compares with that of the United States and to provide operating instructions in case such equipment is acquired for use by friendly forces. Ideally, such tests would also provide insights on how best to counter foreign weapons.

The foregoing objectives imply and justify extensive effectiveness testing, since such tests could provide a basis for improving U.S. capabilities and tactics and would be an inexpensive source of design ideas. Actually, however, military potential tests usually consist of short,

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*The U.S. Army Ballistics Research Laboratories are responsible for estimating the wounding effects of small arms. Tests in support of those estimates have been done by the U.S. Army Chemical Research and Development Laboratories. Wound ballistics testing is discussed in greater detail in Appendix B.

noncomparative versions of standard engineering tests together with informal firings by the Army Infantry Board. (In one case, the FN "CAL" 5.56-cal automatic rifle, a full engineering test was conducted.) Similarly, exploitation tests have been limited, noncomparative firings by the Army Foreign Science and Technology Center (FSTC) also amounting to short engineering tests. These tests may involve as little as one weapon and several hundred rounds of ammunition; formal reports of the results are often unavailable.

Human Engineering Tests

Human engineering tests attempt to examine man-weapon interactions in a controlled but artificial environment from which the "confounding" influences of combat have been excluded. As a result, no claim is made that the environment either looks like or produces the same results as combat. However, the claim is made that the results can provide insights useful for design or combat.

These tests can have little impact on small arms designers because the agencies conducting them (mainly the Army Materiel Command Human Engineering Laboratory, Aberdeen Proving Ground, Maryland) have no design experience and are not associated with designers whom they might serve. Similarly, human engineering tests have little impact on combat, since the testing is not done for users or guided by their needs.

Examples of this type of testing are examinations of the effects of changes in weapon characteristics on aiming accuracy. For instance, some tests have measured the point at which the magnitude of the recoil impulse begins to affect accuracy on a firing range. Other tests have modified existing weapons to maximize performance in one firing mode, e.g., snap-shooting (to the detriment of performance in other combat-critical firing modes). Because the issues addressed and the test conditions are so remotely related to combat, this type of test provides little useful information.

Production Acceptance Tests

The major purpose of production acceptance tests is to determine whether ammunition and weapons meet the technical specifications to which the producer is bound by contract. The usefulness of this testing depends on the relevance of the contractual specifications to the user's needs. On occasion, such specifications have been so incomplete or imprecise that production weapons have been issued that were significantly less effective than the tested preproduction weapons.

The testing is usually done by taking samples of production lots of weapons and ammunition and firing them under controlled, specified conditions. If the samples fail to meet the specifications, the lot is rejected, or the producer is required to submit to inspection of all items in the lot, or the production process is changed.

A critical and sometimes overlooked aspect of production acceptance testing is the interaction between ammunition and weapons. Although a rifle's performance may meet specifications when used with ammunition having certain propellant, case, or bullet characteristics, its performance may be degraded with different ammunition (even though that ammunition meets specifications). Although such interactions should be revealed in engineering and service tests and should be accounted for in production design and specifications, they often are not. It is important that production acceptance tests be conducted with sampled weapon-ammunition combinations that accurately represent the population to be used in combat.

WHO CONDUCTS TESTS AND WHO USES THE RESULTS

Two types of military organizations are concerned with small arms: "users" and "developers." Users are roughly analogous to consumers in civilian life; developers are roughly analogous to producers. However, unlike the civilian consumer, the military user has no marketplace in which to shop for the weapons on which his life depends in combat. He has only one source of supply--the military developer/producer.

To insure that users' needs are met in this monopoly situation, the Army designates a single agency to represent the many users in their

dealings with the developer/producer. This agency is currently the Army Training and Doctrine Command (TRADOC). (The Marine Corps is a semi-independent user agency.) Similarly, a single agency has been designated to represent small arms weapons and ammunitions developers/producers, the Army Materiel Command (AMC).

In theory, the user agency has the responsibility for stating users' needs and determining whether they have been met. The developer/producer agency has responsibility for translating stated user needs into technical specifications; developing or otherwise obtaining equipment that meets the specifications; and supplying the equipment and munitions once the user has accepted them.

The various types of tests defined above are related to this fundamental division of responsibility between developer and user. Some tests help primarily the developer, some the user, and some might be helpful to both. Although of interest to both user and developer, some tests serve primarily as checks for the user on the developer's performance and are appropriate to the necessary adversary relationship between the two organizations.

Engineering design, engineering, and production acceptance tests are of primary interest to the developer/producer. Engineering design tests are exploratory and diagnostic; engineering tests are confirmatory. Service tests and field experiments are of primary interest to the user in adopting developed weapons or selecting among candidates. Field experiments can also lay the basis for stating needs. Service tests confirm that needs have been met. Wound ballistics tests are of interest to both.

The conduct of small arms tests is governed by Department of Defense and Army regulations, which set forth organizational responsibilities, test purposes, and to some extent the content of tests.* These regulations

*These regulations are contained primarily in U.S. Army, Basic Policies for Systems Acquisitions by the Department of the Army, AR 1000.1 (Washington, 5 November 1974); U.S. Army, Test and Evaluation during Development and Acquisition of Materiel, Final draft, AR 7-10 (Washington, 1 January 1975); U.S. Army, Research and Development and Force Development User Testing, Draft, AR 71-3 (Washington, December 1974), hereafter cited as AR 71-3; and U.S. Department of Defense, "Test and Evaluation," Directive 5000.3 (Washington, January 19, 1973), through change 1, April 12, 1974, hereafter cited as DOD Directive 5000.3.

have been changed from time to time, and to understand their current implications it is necessary to review their history briefly.

Before 1962, the designated user agency was the Continental Army Command (CONARC) and the developer agency was the Ordnance Corps. CONARC had as subordinate agencies the Infantry Test Board at Fort Benning, Georgia, which conducted service tests, and the Combat Developments Experimentation Center (CDEC) at Fort Ord, California, which was formed in 1956 to conduct field experiments. Thus, CONARC had both the responsibility of the user agency and the facilities needed to exercise that responsibility.

In 1962, the Army within the continental United States was reorganized into three entities: the Army Materiel Command (AMC), the Combat Developments Command (CDC), and CONARC. The latter was made responsible for training and the administration of the continental U.S. armies. The AMC and CDC were given responsibilities roughly akin to their titles: AMC was charged with the development and procurement of materiel including small arms, and CDC was designated the user agency.

This reorganization had a marked effect on small arms testing. The Infantry Test Board, its name now changed to the Army Infantry Board (IB), became subordinate to the Test and Evaluation Command, which in turn was a subordinate agency of the AMC. Thus, AMC, the developer, became responsible for conducting small arms service tests,* and it became common to combine engineering and service tests.** CDC did, however, retain control of field experimentation through its control of CDEC.***

In 1970, all Armed Forces testing came under fire from a Blue Ribbon Panel established by the President to review DOD organizations.**** In

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*This change also applied to other combat arms and equipment since all test boards were transferred to the Test and Evaluation Command.

**U.S. Army, Organization and Functions: United States Army Materiel Command, AR 10-11 (Washington, 27 June 1968), p. 2.

***For several years, CDEC was known as the Combat Developments Command, Experimentation Command (CDCEC). With the demise of CDC in 1974, its title reverted to CDEC.

****Blue Ribbon Defense Panel, Report to the President and the Secretary of Defense on the Department of Defense (Washington, 1 July 1970), p. 90.

the wake of the panel's report, the DOD issued a regulation dealing with operational testing and evaluation.* It specifies that

> In each DOD component there will be one major field agency separate from the development/procuring command and from the using command which will be responsible for OT&E (Operational Test and Evaluation) and which will: (1) report the results of its independent test and evaluation directly to the military Service Chief, . . . (2) recommend . . . adequate OT&E, [and] (3) insure that the OT&E is effectively planned and conducted.**

The implementation of this DOD regulation in the Army has had an impact on small arms tests. In current DOD and Army regulations the term "operational testing" is used to designate all major forms of user tests (contrary to the Blue Ribbon Panel's and this study's use of the term to mean field experimentation). The regulations define three types of "operational" tests: those that occur early in the development cycle (OT-I), those equivalent to, but more elaborate than, the service tests in previous regulations (OT-II), and those that may take place after type classification or "limited" production and issue to operational units or troop tests (OT-III). For a weapon to continue along the development cycle, it must pass OT-I and OT-II tests.

A separate type of test defined by the new regulation and intended to replace or restrict field experimentation, Force Development Test and Evaluation (FDTE), is stated to be exploratory and not required in the development or acquisition of particular weapons. Its defined purpose is mainly to investigate concepts and organizations.***

To administer operational testing in accord with the DOD regulations, the Army established the Operational Test and Evaluation Agency (OTEA). TRADOC agencies conduct operational testing. OTEA now reports to the

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*<u>DOD Directive 5000.3</u>. It should be noted that the OSD test and evaluation function is assigned to the Office of the Director, Defense Research and Engineering, the major DOD development agency.

**<u>DOD Directive 5000.3</u>, p. 3.

***These definitions are derived mainly from <u>AR 71-3</u>.

Chief of Staff of the Army* and is responsible for planning tests, supervising them, reporting on them, and preparing an "independent evaluation" of OT-I through OT-III tests for major and certain other development programs.** Any agency can propose FDTE. If the proposal is accepted, a test proponent, which need not be OTEA, is designated to plan and conduct it. OTEA has the ultimate responsibility for reviewing and monitoring the tests.

The previous practice of combining engineering and service tests is permitted, though theoretically discouraged, by the new regulations.*** As a result, actual OT-I tends to be superimposed on an early engineering development test. Therefore, it normally occurs too early in the development cycle to provide the user with meaningful information on effectiveness or acceptability. Moreover, the elaboration of OT-II testing means that OT-II occurs later in the development process than previous service tests. Thus, reliance has to be placed on OT-I results in making decisions related to production, and the user gets his first real look at a new weapon too late for his judgment to influence its acceptance.

Another consequence of the Army implementation of DOD regulations is the separation of the responsibility for planning major tests from their conduct. When OTEA was established in 1972 the triadic CDC-CONARC-AMC system was in force and none of the facilities administered by these commands were transferred to it. In 1973 CDC and CONARC were disestablished and their major functions in combat development and training transferred to a new command, TRADOC, mentioned above. TRADOC also became the

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*This is a recent change; it formerly reported to the Deputy Chief of Staff for Operations.

**Major systems are defined as those whose expected life-cycle cost exceeds some dollar value. The arbitrary nature of this criterion is modified by provision for the selection of certain important though non-major systems. If a major new small arm, e.g., an automatic rifle or machine gun, were to be developed, it would probably be selected.

***AR 71-3, p. 47. Though organizations are permitted to conduct combined development/operational tests, DOD regulations discourage it except in the early phases of development where "separation would cause delay involving unacceptable military risk, or would cause an unacceptable increase in acquisition cost." DOD Directive 5000.3, p. 4.

designated user representative for small arms and assumed administrative responsibility for CDEC. In 1974 the combat arms test boards, including the Infantry Board, were also transferred to TRADOC.

OTEA is now responsible for preparing test plans; TRADOC agencies are responsible for conducting the tests. Joint OTEA/TRADOC test teams are envisaged in which the OTEA representative will lead the early planning stages and will become the deputy test director when the outline plan is set. At this point a TRADOC-designated test director will assume control for conducting the test and preparing the test report. Experience indicates that this administrative arrangement is not likely to work well.

ASSESSMENT OF TEST MANAGEMENT AND STRUCTURE

Several problems are associated with the types of tests and the organizational structures just discussed. Some of them appear superficial and semantic. However, all mask real deficiencies that will become apparent to those involved in small arms testing.

The Problem of Terminology

The new regulations governing testing have abandoned the common terms generally used to designate various tests of military equipment. In their place, a set of terms has been introduced (e.g., OT-I, OT-II, OT-III) emphasizing previously neglected aspects of testing that are now easier to implement through instrumentation. However useful that may be, the meanings of terms associated with service, troop, and operational tests have been stretched far beyond their original meanings and now obscure rather than clarify what user testing is.

OT-I, OT-II, and OT-III imply a type of testing for routine weapon development for which there is no need and for which facilities are not available. Thus, OT-I tends to be a shortened service test conducted before the equipment is ready for service testing, and OT-II is a service test that is usually conducted after significant development and production decisions have been made. The one is too early and the other is too late, so the user ends up being unable to influence the weapons development and procurement process to serve his needs.

The Problem of Test Management

To manage the testing process, rather than setting up an independent agency for conducting operational tests and returning service testing to the user, the Army has created an agency that is ostensibly in charge of all testing except development testing. The resources for conducting such tests have been left, however, in the hands of the user. This creates a twofold problem. First, the responsibility for planning all major equipment tests has been separated from the responsibility for conducting them. This diffuses the responsibility for test results to the extent that quality is a matter of luck rather than of effective test management. Second, service testing is still not a user responsibility, so the necessary and healthy dichotomy between user and developer, which was blurred by developer control of user tests from 1962 to 1974, has not been restored. The user is still not responsible for planning and conducting user tests, so it is not clear who has the main responsibility for determining suitability and recommending the type classification of weapons.

The important decision to type classify and procure has been complicated by the establishment of development/procurement panels in the Army and DOD. The Army Systems Acquisition Review Council (ASARC) and its DOD counterpart, the DSARC, have tied the testing process to inappropriate milestones, e.g., very early operational testing, in the development cycle of weapon systems, thus dictating the too-early-too-late pattern of testing noted above. However, as with most management by committee, the practical effect of these panels may be to diffuse rather than to focus the responsibility for development and procurement decisions. Thus, as previously, the user has no clear opportunity to accept or reject the weapons that he must use in combat.

Development Testing for Effectiveness

The foregoing criticism of OT-I is not meant to imply that effectiveness tests of early prototype equipment are not needed or should not be attempted. Service testing, as has been pointed out, is an essential element in the necessary adversary relationship between user and developer.

Calling a service test an operational test obscures this aspect of it, and, further, calling earlier user-developer tests by the same name and making them mandatory implies that the adversary relationship extends to the earlier stages of the development process. This will inevitably cause problems for both user and developer. For the former, it is the danger of de facto acceptance of equipment when there is not enough information to warrant it; for the latter, the danger is comments from the user that are based on the fear of de facto acceptance and on limited technical knowledge. The entire process is likely to be less than helpful to the developer (if taken seriously) and dangerous to the user.

Early prototype effectiveness tests are most useful as cooperative efforts between user and developer. It is difficult to formalize this cooperative arrangement. Thus, such tests are best justified and conducted on a case-by-case basis. When the need for specific effectiveness testing during development is recognized by command levels, a special team could be established to plan, conduct, and analyze such tests. When necessary, DOD-level guidance or funding might be used to help. It should be recognized, however, that this cooperative effectiveness testing early in the development process has very high risks. To succeed, it will usually require extraordinary tactical, technical, and scientific talents.

Chapter III

THE DESIGN AND CONDUCT OF SMALL ARMS OPERATIONAL TESTS

INTRODUCTION

This chapter describes the basic steps in designing and conducting small arms tests. It also identifies sources of further information about them. The discussion focuses on operational tests because they include most of the components of other types of small arms tests.

The steps are presented in the order in which they usually occur in operational testing. But not all steps occur in each type of small arms test, and their relative importance varies from one type of test to another. For each operational test component identified, its application to other types of tests is pointed out.

Chapter IV will illustrate each of these steps by describing the planning and conduct of an actual operational test done at the U.S. Army Combat Developments Experimentation Command, Fort Ord, California, in 1965-1966.

PLANNING THE TEST

The Decision to Conduct a Test

Unlike service and engineering tests, which occur at specified points in the small arms development and procurement cycle and are governed largely by regulation or contract, the conduct of operational tests rests on a one-time decision.

The compelling reason for an operational test is, or should be, the existence of an important question of small arms effectiveness that cannot be answered by reference to combat data, results of other tests, or other types of tests that demand fewer resources. Three other determinations are needed before proceeding with an operational test: that (1) enough resources (e.g., time, money, ranges, qualified test personnel, and test subjects) are available, (2) the weapons and ammunition to be tested are

developed enough that tests in organizational and tactical contexts are meaningful and safe, and (3) weapons and ammunition can be procured in large enough amounts for operational testing.

Thus, the decision to conduct an operational test should be made on the basis of prior investigation, ideally with participation by the nucleus of the team that is to plan and conduct the test. This alludes to another early problem, selection of the agency to plan and conduct the test.

Choosing a Testing Agency

In most engineering and service testing, the testing agency is determined by regulation. That is not true of operational testing. Small arms operational tests are not routinely conducted, and the organizations that conduct other types of tests may not have suitable facilities for operational tests. Moreover, organizations that are required to maintain a small arms operational test facility and expertise in the face of uncertain demand* may not have the money or be able to retain the necessary expertise to do so.

The ad hoc nature of small arms operational tests may argue for their conduct by ad hoc teams independent of the official or conventional testing agencies. The special capabilities and skills required of such a group will be explained in the remainder of this chapter and the next.

The Directive

The preparation of a test directive is the first substantive step in the testing process. The document's most important purpose is to define the goals of the test and the approximate resources available; it may also serve administrative and fiscal purposes.

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*Only two small arms operational tests have been conducted since 1966: the IRUS tests in 1966-1967, which followed up the CDEC-SAWS test, and the XM19-M16 comparisons in 1972. See U.S. Army, Combat Developments Command, Infantry Rifle Unit Study 1970-1975 (IRUS-75), Phase I, AD 870-281L (Ft. Ord, CA, August 1967), hereafter referred to as IRUS-75; and U.S. Army Combat Developments Command, Experimentation Command, XM19 Serial Flechette Rifle Experiment (21.9) (U) (Short Title: USACDEC Experiment 21.9 (U)), Final Report, Vol. 2, ACN 13105, AD 521-236L (Ft. Ord, CA, 26 June 1972), Confidential/NOFORN; hereafter referred to as CDEC Experiment 21.9.

Defining the goals of a small arms operational test is a crucial task for two reasons. First, since operational tests are not governed by regulations or precise definitions, their effectiveness depends heavily on the test team's interpretations of the test goals. Second, once the process is started and the test assigned to a team, it is difficult to influence from the outside. That is partly because operational testing involves concurrent procedures* that make change difficult when plans and schedules have been set in motion.

Thus, the directive needs to be a joint product of the agency defining the need for the test and the nucleus of the test team. It should concentrate on the goals rather than the methods of the test. In many ways it can be viewed as an agreement or contract between the proponent of the test and those who are to plan and conduct it.

Jointly produced test directives are likely to be useful in other types of small arms testing, even though the definition of goals and problems associated with concurrent schedules may not be as critical.

The Test Concept

After the test directive is prepared and issued, the next step is to write a broad statement of how the directive is to be implemented. This statement is prepared by the test team and ordinarily is approved by the test proponent--for two main reasons. First, it may expose misconceptions, misunderstandings, or new factors not adequately addressed in the test directive. Second, it makes explicit the allocation of resources for conducting the test, which usually are only implicit in the test directive. This document should define the rationale for the main elements of the test. They include measures of effectiveness, the organization level, and the test situations.

Measures of Effectiveness

The effect desired from the use of small arms in combat is "fire superiority." Stated another way, the desired effect is (1) to attain

*As will be seen below, training, exploratory firing, and range construction all take place concurrently in a major small arms field experiment.

a level of target effects great enough to beat down the enemy's fire, (2) to achieve these overwhelming target effects as rapidly as possible, and (3) to sustain them long enough so that a mission can be accomplished. The main measures of effectiveness for small arms can be directly derived from this statement. They are (1) the number of targets hit and incapacitated as a function of time from the start of the firefight, (2) the number of targets suppressed as a function of time, and (3) the length of time this level of fire can be sustained with the ammunition that can be carried by the firers. The following paragraphs describe each of these measures.

<u>Targets hit as a function of time</u>. The measure of targets hit as a function of time refers to hitting as many of the available targets as possible and hitting them as fast as possible. It applies whether or not targets are directly seen or located through enemy firing signatures, located by friendly fire tracers and bullet impacts, or located by inference from terrain and tactics. This measure is expressed as cumulative exposure time (CET) and was first used in the CDEC-SAWS experiment. To obtain it, the exposure time of all targets in the enemy array is totaled, from the time a target is first raised until it is first hit. CET can be compared with total "programmed" target exposure time (i.e., the time the targets would normally be raised or exposed in order to perform their firefight functions) to derive a percent reduction in ensuing exposure time that is roughly equivalent to percent reduction in enemy time available for firing.

Targets hit as a function of time is markedly different from traditional measures of small arms accuracy, which tend to be variations of hits per round (including multiple hits on the same target). Hits per round leads to an emphasis on slow, aimed fire and engineering measures such as dispersion or extreme spread of a shot group. These are, at best, indirectly related to combat effectiveness--and certainly not related in any way that can be quantified.

The CET measure is critically affected by how long it takes to locate the target, how long it takes to aim (or point) the weapon, how well the weapon is aimed (including the distorting effects of such conditions as

wind and range), and how appropriate the dispersion pattern is to the spatial disposition of the targets. The foregoing factors are affected not only by the firers' visual acuity, speed, and skill, but also by the characteristics of the weapons.

Targets Incapacitated per Hit (Lethality). Although lethality is normally tested separately in wound ballistics tests, no test assessing small arms effectiveness can afford to ignore what is known about lethality. The available information is reviewed in Appendix B.

Briefly summarized, the evidence indicates that most hits by current standard 5.56-mm and 7.62-mm rounds cause serious, incapacitating wounds. Furthermore, almost no difference is discernible in incapacitation effectiveness among the standard rounds at any of the testing ranges of consequence in small arms combat. The available evidence also indicates that only combat wound data are a reliable basis for estimating incapacitation effectiveness. Even combat wound data must be viewed with caution because they often do not include a record of range or a complete, unbiased, well-identified sample of the most superficial to the most serious bullet wounds.*

For rounds not yet proven in combat, firings against animals can provide useful comparisons of relative lethality, if meticulously controlled for such factors as point of impact, representativeness of ammunition and weapons, and incapacitation criteria. (Such controls have not been exercised since the 1928 Pig Board** firings.) Gelatin block firings, traditionally widely used, cannot be validly translated into absolute or relative lethality comparisons. Currently used models for incapacitation probabilities, which are based in part on gelatin block firings, yield results that conflict with both combat data and experiments with animals.

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*For instance, the often-quoted World War II casualty figures ascribing 75 percent of the casualties to artillery and mortar fire are based on a sample of approximately 200,000 living wounded cases. On average, bullet wounds result in a much higher percentage of fatalities than fragment wounds. KIA are rarely accurately diagnosed as to cause of death.

**Board of officers appointed to recommend a specific caliber for the future development of the semiautomatic shoulder rifle. See U.S. War Department, Pig Board, Report of the Board of Officers Appointed by Paragraph 31, Special Orders 154, War Department 2 July 1928 (Washington, September 21, 1928).

Suppressive Effects (Near Misses as a Function of Time). Although it is known that suppression is an important factor in reducing enemy fire and movement, little is known about the suppressive effect of near misses at various distances and positions relative to the target (e.g., visible hits in front versus to the side, audible near misses above versus to the side).* Nor is much known about the duration of suppression, that is, whether one round every two seconds or one round every ten seconds is needed for effective suppression.

In the absence of more definitive knowledge, near misses within 3 ft are assumed to be suppressive, and the total number of 3-ft near misses is usually taken as the measure of suppression effectiveness in operational tests. A slight improvement might be obtained by using a curve of total target suppression time versus assumed suppression time per round (where the assumed suppression time ranges from 1 second to 10 or 15 seconds). This would have the effect of introducing time and discounting several almost simultaneous near misses from the same burst.

Sustainability (Duration of Fire). The length of time over which the target effects previously described can be sustained, given the ammunition load that infantrymen can carry, is another measure of effectiveness. To calculate it, small arms must be compared in equal weights of weapon systems, i.e., weapon plus accessories plus magazines and ammunition. The weight chosen for comparing small arms will depend on the infantry's mobility and non-weapon load requirement imposed by the tactical situation. A three-week, self-sustaining reconnaissance patrol may be able to afford only 12 lb of a small arms systems, while a mechanized infantry squad fighting within 500 meters of their APC may be able to afford 25 lb. A nominal weapon-system weight for a rifleman is usually taken as 17 or 18 lb.

Given an appropriate weapon-system weight and the number of rounds available within that weight, the duration of sustained fire in a given experimental situation is easily calculated from the length of the firing and the rounds expended.

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*One of the few experiments that bears on this question gives results suggesting that soldiers in foxholes cannot distinguish reliably between 4-ft and 8-ft misses and that misses low and to the side are better distinguished than are misses overhead.

Other Measures of Effectiveness. The reliability of a small arms weapon has importance beyond its impact on target effects. If a weapon is unreliable beyond a certain level, troop morale and confidence are impaired. The level cannot be specified precisely (nor can firing cycles and environmental conditions that are repeatable and representative of combat reliability conditions be specified precisely), but failure rates of 10-20 per thousand rounds* for selective fire weapons in field experiments have been found excessive in the past.

The tracer effectiveness of a small arms weapon-ammunition system, that is, the visibility of the trace for helping to distinguish the target (and for aiding weapons pointing), has a significant effect on infantry small unit effectiveness.

Training effectiveness, i.e., the ease with which "average" riflemen can be trained to combat proficiency, is important because (1) rifle training resources are rarely adequate under wartime conditions, (2) learning in combat is costly, and (3) combat learning time is limited by the fact that few riflemen survive more than five or ten intense firefights.

Weapon detectability (e.g., muzzle flash, smoke, and dust) becomes important when the firing signature is so visible that firer survivability is impaired. It is not clear that current standard small arms differ significantly in detectability.

Application to Other Types of Tests. The foregoing measures of effectiveness are as relevant to the design of a weapon as they are to comparing weapons in field experimentation. As such, they need to be considered in developer testing as well as in user testing although the extensive resources necessary for in-depth measurement of effectiveness in a realistic organizational and tactical context are not available for developer tests. Almost none of the major small arms measures of effectiveness are addressed in current developer testing, except reliability (and occasional attempts to examine lethality, weapon signature, and tracer visibility). There may be considerable utility in devising simplified effectiveness

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*This represents one failure per 25-50 two-round bursts, a level that could be burdensome in combat.

tests to provide the designer with early insights into the effectiveness of new prototype weapons, though they have not been a traditional part of engineering development testing.

Service tests of new small arms have traditionally included some firing on "tactical" ranges to obtain approximate effectiveness comparisons aginast control weapons. Measures used generally emphasized total hits and hits per round. Since the establishment of the Infantry Board instrumented ranges in the late 1960s, Infantry Board tests have sometimes included near misses and cumulative exposure times. However, the design of the Infantry Board ranges and the conduct of the tests on them have restricted the validity of the results of their effectiveness tests (see Chapter V).

Because of the heavy demands effectiveness testing makes on resources, it is neither feasible nor desirable to have service tests include full-fledged effectiveness experimentation. Whether practical, simplified, and valid effectiveness testing procedures can be devised for service tests remains an open question.

Selection of Organizational Level

The selection of the organizational level at which a test is to be conducted must consider both the objectives of the test and the resources available. No test of small arms effectiveness can achieve a totally realistic representation of the full setting of infantry combat. To do so would require simulating enemy and friendly artillery and tank and engineer support--an enterprise that would require testing at battalion or brigade level, at least.

On the other hand, there are strong interactions between adjacent riflemen that directly influence the absolute and relative effectiveness of small arms. Ejection of hot brass may disturb the aim of adjacent firers. The bullet strikes of other riflemen and machine gunners interfere with the adjustment of fire on targets. Tracer fire from a particularly quick and keen-sighted riflemen helps draw the fire of his squad to important, hard-to-see targets. There are undoubtedly other unknown interactions between small arms firers that may have even greater impacts on effectiveness than these examples.

Thus, for the operational testing of small arms effectiveness, firing by individual riflemen is not likely to give valid results. The next higher organizational level that could be considered is the squad. (Fire teams within squads are precluded because combat experience indicates that no such organization actually functions in combat.) Squad-level testing appears to incorporate many of the significant interactions between small arms firers in combat, since adjacent squads normally operate against separate parts of the enemy target array (unless squads are providing a supporting base of fire for other squads). Appropriate target arrays for squad-level testing are platoon-company arrays, that is, target dispositions that include machine gun support, forward observers, platoon leaders, radio operators, and messengers.

The next higher level of testing that might be considered is the platoon, at least to the extent that two squads, one supporting and one advancing, might be tested. Whether including this interaction would significantly improve absolute or relative effectiveness evaluation is unknown. What is known is that it would pose serious safety problems, would greatly increase the terrain required for safety fans, and would more or less double the number of test subjects required. Since thorough squad-level operational testing already requires 300 to 1000 test subjects, it does not appear practical to increase the organizational level for small arms testing to platoon level--nor do the advantages of such an increase in level appear significant.

Test Situations

When the measures of effectiveness and organizational level have been defined, representative combat situations within which to evaluate the measures must be selected from the spectrum of possible small arms combat situations. The design of the test target system and firing conditions will be determined by the situations selected.

Types of Small Arms Combat. Infantry small unit combat can be grossly categorized into three main types: (1) attack, where infantry squads attempt to displace the enemy from his more or less prepared positions, (2) defense, where the obverse occurs, and (3) a less well defined type

of combat variously called meeting engagements or approach to contact. The latter mode involves engagements in which neither side has prepared positions. It occurs frequently when screening forces or advance units move through lightly occupied or patrolled areas and where the occupier attempts to slow down, disrupt, or channelize the movement.

Within these three types, a minimum number of representative situations need to be selected for rifle squads and machine gun squads (where applicable to the test at hand) and for day and night combat. Situations in which firing conditions, targets, and distances are similar can be eliminated. A useful selection of representative combat situations for an actual operational test is described in Chapter IV.

Design of the Test Situation. Small infantry units in each selected situation follow specific patterns of organization, disposition, firing, and movement. They are determined mostly by the situation, the terrain, and the weapons, and somewhat by the doctrine of their array. By thorough analysis of the small unit combat experience and doctrine of friendly and enemy forces, followed by gaming using topographical maps or sand tables, it is possible to synthesize valid, representative terrain, dispositions, and target array and firer behavior for each situation. In making this synthesis, it is particularly important to set the target range at distances actually encountered in combat, to avoid the widespread tendency to test small arms at unrealistically long ranges.

Given a specific map description of appropriate terrain, dispositions, distances and behavior of targets and firers in each combat situation, the design of the test situations proceeds by (1) selecting actual terrain that corresponds to the synthesized terrain derived for the situation, (2) selecting actual firer and target locations (and cover) on the terrain by further gaming, using tactically experienced personnel, (3) emplacing targets and firing positions, and (4) programming target appearances (including their firing simulators) together with firer actions to provide sequences of sight and sound cues that are as representative as possible of actual firefights.

Careful attention must be paid to achieving realistic target-firer interactions. The most obvious interaction, attrition, is usually simulated

by targets that react to hits by going down. The second interaction, the appearance of suppression, can be simulated in two ways. First, targets that are not hit can be programmed to go down after a length of time considered a realistic exposure time for targets under fire; second, targets not hit can be made to go down after a certain kind or number of near misses. Both methods involve assumptions about troop reactions to fire that are more tenuous than those on which the simulation of attrition is based, and it is difficult to choose between them. Programming targets to stay up for a certain length of time unless they are hit is less complicated mechanically and more repeatable. But it provides target cues--e.g., targets up after they actually would have been suppressed--that might not be there in combat and that may distort the distribution of fire.

The third interaction is that of target appearances in response to firer movement, e.g., targets that pop up and fire when the firers reach a certain position along their route of advance. The main interaction that has not yet been successfully simulated is the suppressive effect on the firers of return fire from the targets. Since there is no actual threat to the firer, he has less incentive to take cover than he might in combat. This, in turn, probably leads to quicker, more assured target acquisition and more accurate fire than would occur in combat. Since such factors may bias test results against small arms, which, other things being equal, can fire more quickly and with less firer exposure, they must be carefully guarded against. If it cannot be done in the test by control of the firers' positions, it must be done in the analysis of test results.

Information pertaining to the design of test situations is scattered throughout a variety of sources. Detailed historical observations of small unit actions are sometimes available in archival material; the main published sources are the works of S. L. A. Marshall. Doctrinal discussions appear in the field manuals of most armies. Appendix D gives a summary of the information available on target range frequencies for small arms combat. Appendix E gives insights drawn from combat film regarding firers and, to some extent, targets. Of interest are the findings about the use of pointing fire and the speed with which aiming takes place. Also relevant is the finding that line-of-sight obstruction due to terrain and

vegetation near the firer makes prone firing less frequent in combat than in testing. Thus, testing must provide as much for cover and concealment of the firer as it does for concealment of the target. For detailed depictions of carefully researched and gamed small arms firer/target arrays, one of the only available sources is the report of the CDEC-SAWS experiment.*

Application to Other Types of Tests. The extensive planning required to select and design appropriate test situations is not needed in tests that have no effectiveness component. For service tests and engineering development tests that do consider effectiveness, some degree of the planning effort described above will be needed--even if the ultimate situations and arrays are much simpler than those necessary for operational testing.

Experimental Design

The experimental design roughly establishes the number of test subjects or squads, the "balancing" of subjects of varying abilities among the candidate weapons, and the amount of firing and the sequence of firing conditions (i.e., the experimental "matrix") for the test. The object is to assure that actual differences in the material being tested can be identified and distinguished from differences arising from chance or other factors. This is a particularly difficult problem in operational tests because the test situations inherently contain a large element of chance variability, particularly in the acquisition of hard-to-see targets. Further, experience has shown, no matter how carefully squads are selected through aptitude testing and qualification firing, large differences in the effectiveness of squads using the same weapon will be seen--differences that are normally larger than the differences between candidate weapons.**

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*U.S. Army Combat Developments Command Experimentation Command. Small Arms Weapon Systems (SAWS), Part 2: Annexes, CDCEC 65-4 (Ft. Ord, CA, 10 May 1966), hereafter referred to as CDEC-SAWS Annexes; idem, Small Arms Weapon Systems (SAWS), Part 1: Main Text, CDCEC 65-4 (Ft. Ord, CA, 10 May 1966), hereafter referred to as CDEC-SAWS Main Text.

**A recent example of this was CDEC Experiment 21.9, where a careful selection procedure did not prevent wide differences in firing proficiency among fire teams.

Thus, the test sample must be large enough to measure weapon differences, if they exist, over and above the "noise" due to chance factors and differences in subjects.

The Test Subjects

Two basic questions that often arise in the design of small arms tests are whether the same test subjects can be used to fire different weapons and whether they can be used to refire the same ranges. If they can, far fewer test subjects would be needed. In fact, neither is feasible in valid operational testing.

This question opens the door to a series of other questions about the management and use of test subjects. First, it is important to recognize that the motivation of test subjects will dominate test results, if left uncontrolled. This motivation can be strongly influenced by the subject's attitude toward the weapon he is firing. Also, his prior training on other weapons can significantly influence his performance. Thus, not only should the same test subjects not be used to fire different weapons,* but the entire relationship between test subject and weapon is a possible source of bias in the test.

To control for such bias, test subjects should, if possible, receive their initial marksmanship training on the weapon they are to fire in the test. If that is not possible, retraining to the new weapon needs to be longer and significantly more intensive than the subjects' basic and advanced individual training to overcome prior familiarization. Subjects also need to be shielded from adverse comments about the weapon they will fire; the personnel who train and supervise them should be taught (and monitored) not to consciously or unconsciously influence them because of their own beliefs.

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*Some data on this subject comes from a series of similar tests on the IB ranges between 1965 and 1970. In some tests the test subjects had received their initial training on the M14 and then were retrained on the M16; in these tests the M14 scored better than the M16. In the last test, subjects were used who had received all their initial training on the M16 and then were retrained to fire the M14. The M16 scored significantly better than the M14 in these tests.

A final caution is to insure that the test subjects do not learn the target system or the range before being tested on it. This is to preserve the essential "unfamiliar range" characteristic of combat. It implies, first, a need for tactical training ranges that are separate from the testing ranges and, second, the separation of units that have fired a given range from those that have not. The subjects must be made thoroughly familiar with tactical unit firing on the tactical training range; otherwise, strong learning effects will take place on the testing range and will bias results.

Size of the Sample

If full knowledge of statistical variability due to subjects' ability, lighting, wind, chance target acquisition, etc., were available, the required sample size could be determined mathematically. Since this presumes knowing the outcome of the test (and the influence of all factors), obviously statistical calculations will not help much. Thus, selecting the number of test subjects has to be based on intuition and the experience of previous tests. The only general numeric guideline is that the smaller the differences that need to be measured between alternative weapons, the larger the number of test units needed for each alternative--up to a practical upper limit of the number of people who can be managed in training and indoctrination. Judging from squad variability in the CDEC-SAWS experiment, six squads per candidate weapon mix was barely adequate for determining the general differences between 7.62-mm and 5.56-mm weapons; it was inadequate for distinguishing among the various 5.56-mm alternatives.

Application to Other Types of Tests

The foregoing considerations apply to all other types of tests that consider effectiveness.

Other Early Planning Tasks

While the test concept is being prepared, several other steps are taken early in the planning. The most important is the selection of the terrain on which the test is to take place and the determination of

instrumentation requirements. Both require a thorough understanding of the test concept, and decisions about them must remain somewhat tentative until the test concept is finished. However, the problems involved in both matters are potentially so time-consuming that early decisions are usually required.

Since the time of the 1965 CDEC-SAWS test, both CDEC and the Infantry Board have built test range complexes providing terrain and instrumentation for the conduct of operational tests. These facilities should be considered first in determining the location of an operational test. Chapter V and Appendix F provide data to help assess the adequacy of the CDEC and Infantry Board facilities. The following discussion of terrain and instrumentation applies in case CDEC or Infantry Board facilities are not available or must be significantly modified.

Choosing the Terrain

The criteria used in selecting appropriate terrain should derive from the synthesized test situation. The reverse is often done--fitting the test situation to the terrain available--but is unlikely to result in representative or valid test situations. Training ranges where cleared fields of fire exist out to 350 meters are not the type of terrain needed. What is more appropriate is terrain permitting the location of defensive positions on the military crest of a hill but providing access for assault within 50-100 meters of the positions. It is as important to provide cover and concealment for firers as for targets in order to have realistically obstructed lines of sight. Approach-to-contact ranges with adequate target concealment are also required. The range safety fan requirements of both types of ranges can present severe problems. Finally, although it may appear self-evident, all ranges should be located reasonably close together. Test management is difficult enough without being complicated by great distances between the various ranges.

Determining Instrumentation

Significant improvements in instrumentation since the early and mid-1960s have made operations that were then difficult and costly now easier

and cheaper to do. They include computerized control of the target system, recording and preliminary sorting of data. On the other hand, problems such as the preservation of cabling, measurement of near misses, and the recording of shots fired in moving situations without interfering with the firer are no nearer solution than they were then. Chapter V and Appendix F discuss in greater detail the availability and performance of instrumentation devices.

Application to Other Types of Tests

Selection of terrain and instrumentation will be equally significant problems in other types of small arms tests considering effectiveness.

Detailed Planning and Range Preparation

After the test concept has been approved, detailed planning and preparation of the range begin. At this point the team's work shifts from mainly conceptual activities to practical matters of the management of many support personnel and the construction of field facilities. Many of the design elements that were stated only generally in the conceptual stage must now be described in detail. They are discussed below.

Firing Doctrine

Small arms weapon systems that are important enough to justify an operational test will generally include weapons that have quite different technical characteristics and configurations. This, in turn, implies that the best firing doctrine and techniques will be different for each weapon (and possibly for each situation). For new weapons they may not be well known. To insure that, if not already established, the best firing doctrine and techniques are used, trial firings should be made by experienced firers on instrumented tactical ranges similar to the test ranges. The trials may be more or less elaborate depending on the problems involved; they will need to determine such factors as best burst length, best tracer-to-ball mix, desirability of aiming versus pointing the weapons, and best sight setting.

Range Installation

For ranges large enough to test squad-sized units, installation of the range is a major construction task that must be done carefully to preserve the integrity of the terrain. One of three approaches can be taken, depending on the test design. The first is to pay little attention to whether installation disturbs the terrain, smoothing the surface afterward and not trying to conceal the location of the targets and cueing devices. Realism, to the extent it exists when a range is installed this way, is provided to the firers only by combat-like firer-target distances, unexpected target appearances, and random (rather than logical) sequences. This is, with minor exceptions, the way the current CDEC and Infantry Board ranges have been installed.

A second approach is to maximise the amount of disturbance of the terrain so that the firer can see no clear pattern of where targets and cueing devices are located. Firers have experienced great difficulty in both spotting where targets are located and remembering where they appeared when faced with this type of confusing, disorganised terrain.* However, there can be little claim that any particular type of combat is being simulated when the target system is installed this way.

The third approach is to disturb the terrain as little as possible and to restore it to its original form for the test itself. Although this requires a great deal of care (e.g., digging by hand, removing dirt in sandbags), it is the only way to assure that weapons can be tested in representative combat situations. Since that is a major aim of an operational test, the care would seem to be justified.

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*This occurred in the SALVO I and SALVO II experiments. See Johns Hopkins University, Operations Research Office, Tactics Division, SALVO I: Rifle Field Experiment, by Leon Feldman et al., Technical Memorandum ORO-T-378, AD 304-321 (Bethesda, MD, June 1959), and idem, SALVO II: Rifle Field Experiment, by Leon Feldman et al., Technical Memorandum ORO-T-397, AD 325-385 (Bethesda, MD, May 1961). Hereafter referred to as SALVO I and SALVO II, respectively.

Test Matrix

The test matrix must be produced and initially balanced.* Factors to be considered in this process are all the environmental and learning factors that might affect the outcome of individual trials.

Because the acquisition of hard-to-see targets is an integral part of effectiveness in small arms combat, changes in lighting will completely change the character of, and results from, a given tactical range. To reduce these variations, it may be helpful to have target systems facing south (to be fired on from the south). However, it is usually necessary to accept a less than ideal orientation; even when it is achieved, the test matrix must be balanced for the position of the sun.** To take account of the effects of wind and visibility, such things as on-range measuring devices, record-taking, and threshold criteria for canceling tests will be needed.

A final task in the detailed test design is to assure that the testing situations have been balanced in their order of appearance and presentation to the test units. Learning can occur not only within a given situation (if repeated) but also across modes. For example, a unit that fires the attack range first and the defense range second might do better on the defense range than would a unit that is seeing this type of target system or participating in a test firing situation for the first time.

Test Subjects

Operational tests usually involve the training and use of test subjects over many months, and it is important to maintain the same test population throughout. Insuring this continuity may be more difficult than it might seem. A stable test population will have many unprogrammed demands made on it, including sickness, appointments to schools, and tour of duty rotations. Often only administrative action at a fairly high organizational

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*As unprogrammed events occur during the test, e.g., bad weather, the matrix will become unbalanced. The need to rebalance or make accommodations has to be allowed for in the initial detailed design.

**Such balancing problems can be very difficult to handle, considering the natural variation of the cloud cover and the effects it may have on lighting conditions.

level can prevent unacceptable changes in the test population. Even so, attrition from sickness and other unavoidable causes can be handled only by training many extra firers as possible replacements in test units. It is prudent to provide for one-third or more replacement firers for a six-month operational test.

After authority is given to stabilize a test population, the next step is to select the test subjects. As has been pointed out, it would be ideal to choose subjects who would receive their first small arms training on the weapons they would use in the tests. This implies selection before the subjects' basic training. Although there is no particular reason why this cannot be done, it is obviously administratively difficult, and there is no record of its having been done for any small arms test.

As it has been impossible to select firers whose small arms experience would begin with the weapon assigned to them in the test, criteria usually used are standard rifle marksmanship scores, military experience, physical measurements, eyesight, left- and right-handedness, and general intelligence and aptitude scores.* Extra firers are selected in the same ratio of personal characteristics as the test-subject population.

Training

Training should insure that each weapon is equitably treated and that prior experience with standard weapons will not bias results. This implies substantially longer than normal training on all weapons to bring firers up to equal levels of proficiency and to minimize the effects of prior training. It also implies a formal training curriculum, training ranges, and training cadre. How closely should this training program parallel the regular training system? Clearly, at some point, firers will have to be taught the best firing doctrine for their weapon--as determined by the exploratory firing trials. At least at this point, training will be forced

*Balancing by means of these criteria is done merely to avoid any hidden bias; personal criteria should not be expected to be good predictors of performance.

to deviate from the standard training curriculum in the interest of using such weapons most effectively.

Weight Constraints

Weight is a major difference in alternative small arms systems, and test planners must decide how this variable is to be treated. It can be done in basically two ways. The first is to give the firers unlimited ammunition during the test proper and then to normalize to a given combat load in the analysis stage. This method has the advantage of simplifying training and the conduct of the test. On the other hand, it can result in unrealistic (and unequal) individual mobility. It also can lead to a different distribution of fire than if firing doctrine were strictly tailored to a fixed-weight amount of ammunition made available for the alternative weapon systems. Thus, although it adds another source of potentially significant variation and complicates training, limiting the amount of ammunition available for each firing situation by total systems weight appears to be the only valid procedure for comparative small arms testing.

Detailed Scenario Design

After the target system has been laid out--e.g., the target locations marked, surveys performed, and firer-target intervisibilities checked--the targets with their target cueing devices are installed. Then, the program controlling target appearance and simulated firing is checked out, using exploratory squads of firers. This is done to ensure that these programs do produce a realistic buildup of fire intensity and realistic target exposures (including the effect of targets knocked down) and target sequences. Besides the visual-aural "fine tuning" provided by these target program checks, they also provide the first batch of test data, useful in checking sample sizes, instrumentation, and variations in test data.

Application to Other Types of Tests

Although the detailed plans for operational tests are much more voluminous than are those for service or engineering tests, the principles discussed above apply to all types of small arms tests.

CONDUCTING THE TEST

Ideally, the conduct of a small arms test is merely the execution of a detailed plan. This is rarely, if ever, the case. Most operational tests arise from needs for new information in conditions that are difficult to simulate and control. As a result, each is usually unique in major respects, so it is virtually impossible to prepare a plan that can foresee everything that will occur in the field. Test managers have the responsibility of evaluating how closely the execution conforms to the plan, recognizing mistakes or defects in the plan and making changes when necessary. Measures to help identify and deal with unexpected problems during field experiments include keeping a detailed record of the experiment and exercising quality control over the data. These methods are also applicable in principle to service and engineering tests.

Documentation

The detailed planning of the test will have produced forms and instructions for conducting and recording field activities. There will be a large number of them, and they will be most serviceable if they are in a consistent format.

As they are implemented, the detailed operating instructions form the basis for a history of the experiment. It is important to record any changes, and the reason for them, that are made in these instructions--as they occur. The reasons are, first, to make the proposed changes available for daily review by the experimental team (and to minimize their adverse impact on validity) and, second, to provide a complete record for later use in analyzing the data collected.

Quality Control of Data

In any field test or experiment there is always the chance that data collection devices or procedures may not work as planned (or that the planning did not adequately foresee all the problems of data collection). Such malfunctions or inconsistencies may be masked and difficult to recognize merely by an examination of raw data. Thus, cross checks, and preferably an external check of the data sources, are needed while a test is under way.

In small arms tests several obvious measures can be taken. Instruments needing calibration must be checked frequently, preferably at a certain time daily, with calibration records collected and preserved. If rounds fired are counted electronically, the electronic counts need to be checked against manual counts of ammunition expended. Electronically recorded hits can be checked against manually counted holes in targets. Motion pictures taken during a run can be used to ensure that events take place as planned. Redundant instrumentation circuits can report range events such as when a target went up and when it went down. Finally, logic checks must be made between data sources. For example, are hits recorded when targets are not exposed, or are total hits plus near misses greater than the number of rounds fired?

All measures for controlling data quality must be timely. If the results of checks are not provided soon enough to ongoing operations, they lose much of their utility. Yet, counting holes in target faces is slow--particularly when great accuracy is required--and very difficult at night. The use of photography is also slow--first in the developing of the film and second in its analysis. Thus, specific measures have to be designed to fit the nature of the individual experiment or test.

Range Maintenance

Firing (or uncontrolled personnel movement) on a test range causes progressive deterioration of the terrain around the targets. A major problem in tests simulating combat conditions is the maintenance of a consistent appearance in soil and vegetation so that later firers have the same difficulty in detecting targets as earlier ones did and so that they receive the same feedback from their own bullet strikes. Only thus can the data from all trials of a given test condition be aggregated and compared.

Care must be taken to preserve the terrain at firing points, where interfering vegetation can be shot away--giving firers better visibility--and the surface of the ground can be loosened by repeated muzzle blasts, creating excessive dust. A potentially catastrophic problem is the likelihood of fires that can destroy the range. Tracer ammunition starts fires very easily in dry vegetation.

Experience has shown that range characteristics can be kept constant by assigning the responsibility to one person as a primary task and giving him adequate support in photographic services, fire crews, range maintenance crews, and sprays to treat soil and vegetation. Determining when range characteristics have actually changed requires detailed baseline photography and a constant watch by someone having intimate familiarity with the visual details of the range.

Weapon Maintenance

Two aspects of weapon maintenance are important to small arms service tests and operational experiments but are of little concern in engineering tests: identifying maintenance problems associated with the field use of the weapon by infantry units, and keeping the test weapons operating so as to truly represent the combat abilities of each weapon-ammunition system.

Test subjects need to be trained in the normal care and cleaning of their weapons and in clearing stoppages and overcoming routine malfunctions. Weapon maintenance specialists on the company level (called "armorer-artificers") should be trained in the repair functions they normally perform. Control personnel must supervise test subjects' activities to ensure that they validly represent the type and quality of work that an infantry unit would be expected to perform in the field. They should also see that data are kept on the subjects' success in keeping their weapons operating in the field. They must be alert to incipient maintenance problems so that data collected on weapon performance are not biased by an excessive number of malfunctions that do not represent a weapon-ammunition combination's expected level of performance. The type of malfunction referred to is an unrepresentative deviation of some part, adjustment, ammunition characteristic, magazine or link characteristic, or weapon characteristic that causes excessive failures during firing tests. Measurements of the time taken to correct malfunctions are important in assessing effectiveness. A major additional training load is the need to train armorer-artificers not only in maintenance but in correct and consistent diagnosis of causes of malfunctions.

The work of armorer-artificers, control personnel, and technical representatives must be thoroughly coordinated in the collection of data on malfunctions so that the character and seriousness of each one is identified, apparent causes recorded, and safety insured.

ANALYZING THE TEST

Analysis begins with the production of the first raw data, whether from trial runs, training, or from the test itself. It consists of data reduction and analysis proper. The general form of these two activities is usually prescribed in the test design.

Data reduction is the process of taking the measurements recorded during a test and arranging them so that statistical analysis can be applied and their general import can be understood. This can be done manually, but more commonly it is done by computer manipulation of the data, producing printouts of target-system and firer events as a function of time.

Data reduction will usually reveal deficiencies in the data. They characteristically have to do with events that should have taken place but did not, events that took place but were not recorded, or records of false events. Methods will have been devised before and during the test for dealing with these problems so as to preserve as much valid data as possible. (Sometimes it can be shown that several logical alternative treatments of "problem" data do not change the results of the overall statistical analysis.)

The statistical analysis itself can take many forms; some of the widely accepted, standard analytic techniques can be shown to be invalid. Insufficient emphasis on the magnitude and causes of variations in the behavior of individual subjects (or squads) is a frequent weakness of statistical analyses in small arms testing.

REPORTING THE TEST

A common problem in the reporting of small arms (and other) tests or field experiments is the failure to publish the main body of test data. There are several levels at which this can be done. The most complete publication includes the raw data, the experiment's day-by-day log, and the methods used in data reduction. The sheer volume of this information makes it difficult to put in a single report. A more practical alternative is to report the reduced data on which the statistical analysis is based. Regrettably, many reports contain only data summaries and selected statistical results of the analysis.

Most small arms testers tend to view their objectives narrowly and attempt to answer only the questions stated in the test's scope and purpose. However, field experiments, being so comprehensive, provide data for analysis beyond the specific questions posed, giving insights into questions at first only implied. Later, when new questions arise, the full body of data from a test is often useful in answering questions that were not imagined at the time the test was conducted. Because of this, field test data are used (and sometimes misused*) for a variety of purposes and for a long time.

It is especially important in small arms testing to document fully such supporting matters as the selection and training of test subjects; rationale for range layout, test situations, and target programs; representativeness of the sample of weapons and ammunition; calibration of instrumentation; and validity checks on electronically collected data. Because defects in any of these matters could invalidate an entire test, it is essential for credibility that they be included in the test report.

Finally, the report should be organized to facilitate the understanding and use of the experimental data by readers. This may seem self-evident, but the use in recent years of "executive summaries" to sell the conclusions resulting from the analysis of experimental data has degraded

*Detailed publication of results tends to minimize opportunities for inadvertent misuse.

the quality of experimental reports. Such executive summaries are sometimes supported by badly organized, incomplete supplements that make further use of the experimental data difficult if not impossible.

Chapter IV

A CASE STUDY OF THE COMPONENTS OF SMALL ARMS TESTING: THE CDEC-SAWS FIELD EXPERIMENT

INTRODUCTION

To provide practical insights into the implementation of the components of small arms testing, it is useful to examine in detail an actual operational test of small arms. The 1965-1966 CDEC* Small Arms Weapon System (SAWS) Field Experiment is an apt example for several reasons:

- o CDEC-SAWS was a major field experiment that included most of the elements of small arms testing described in Chapter III. It incorporated both effectiveness testing and extensive engineering testing.
- o CDEC-SAWS involved pioneering advances in the effectiveness testing of small arms and was probably the most carefully controlled field test conducted to date.
- o The details of the planning and execution of CDEC-SAWS have not been compiled or published previously; thus, the case study represents a contribution to the literature of small arms testing.

This chapter is based on a review of the few documents remaining in the CDEC-SAWS archives, the personal files of the main participants, and recorded interviews and correspondence with these participants. The material is presented so as to illustrate the practical experience gained from conducting the test as well as to illuminate the basic components

*This facility has undergone several changes of name and abbreviation since it was established in 1956 (see pp. II-10f.). Though in 1965-1966 it was abbreviated CDCEC, this study hereafter adopts the simpler and current abbreviation, CDEC, to refer to the field experiment described in this chapter.

of small arms testing discussed in the previous chapter. Conclusions and quantitative results of the CDEC-SAWS experiment are not discussed here; they appear in the formal SAWS report.*

The chapter begins with the background of the experiment, then proceeds to describe its planning and preparation, the organization and construction of the testing range, and the experimental firings themselves. It concludes with a discussion of the analysis and reporting of the data.

BACKGROUND

In late 1964 the Department of the Army decided to conduct a major small arms field test to compare the effectiveness of the M14, the M16, and the Stoner rifles. This decision was spurred by the growing controversy over the relative effectiveness of the 7.62-mm M14 and the 5.56-mm weapons. The Secretary of Defense had already cancelled M14 production, despite Army objections. He also had equipped the Special Forces in Vietnam with the AR-15, the privately designed, commercial predecessor of the M16. The Marine Corps had conducted engineering and service tests of the Stoner family of weapons that showed significant advantages over the M14.

Thus, CDEC-SAWS was initiated in an atmosphere of high-level controversy, intensified by the emotions traditionally associated with the selection of a new rifle. Under these difficult circumstances, CDEC was given the task of conducting the field test to provide a scientifically valid basis for Department of Army and OSD cost-effectiveness comparisons and decisions concerning the competing small arms.

CDEC had been established in 1956 to develop and conduct field experiments for a whole range of Army weapons. Although CDEC had no previous

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*U.S. Army Combat Developments Command, Experimentation Command, Small Arms Weapon Systems (SAWS), Part 1: Main Text, CDCEC 65-4 (Ft. Ord, CA, 10 May 1966), hereafter referred to as CDEC-SAWS Main Text; U.S. Army Combat Developments Command, Experimentation Command, Small Arms Weapon Systems (SAWS), Part 2: Annexes, CDCEC 65-4 (Ft. Ord, CA, 10 May 1966), hereafter referred to as CDEC-SAWS Annexes.

experience with large small arms field experiments, it possessed the resources necessary for a major small arms field test, including the large military reservations at Fort Ord and Hunter Liggett, an experimentation support group [illegible] test instrumentation, and the 3000 men of the 194th Armored Brigade for test subjects.

PLANNING

The Project Team

The project team was initiated with the selection of a team chief, who in turn selected a deputy and was provided with a project scientist. In February and March 1965, the team grew to a strength of 17 officers and 13 enlisted men. It later expanded to 19 officers and 21 enlisted men, plus civilian professionals and support troops (identified later in this chapter).

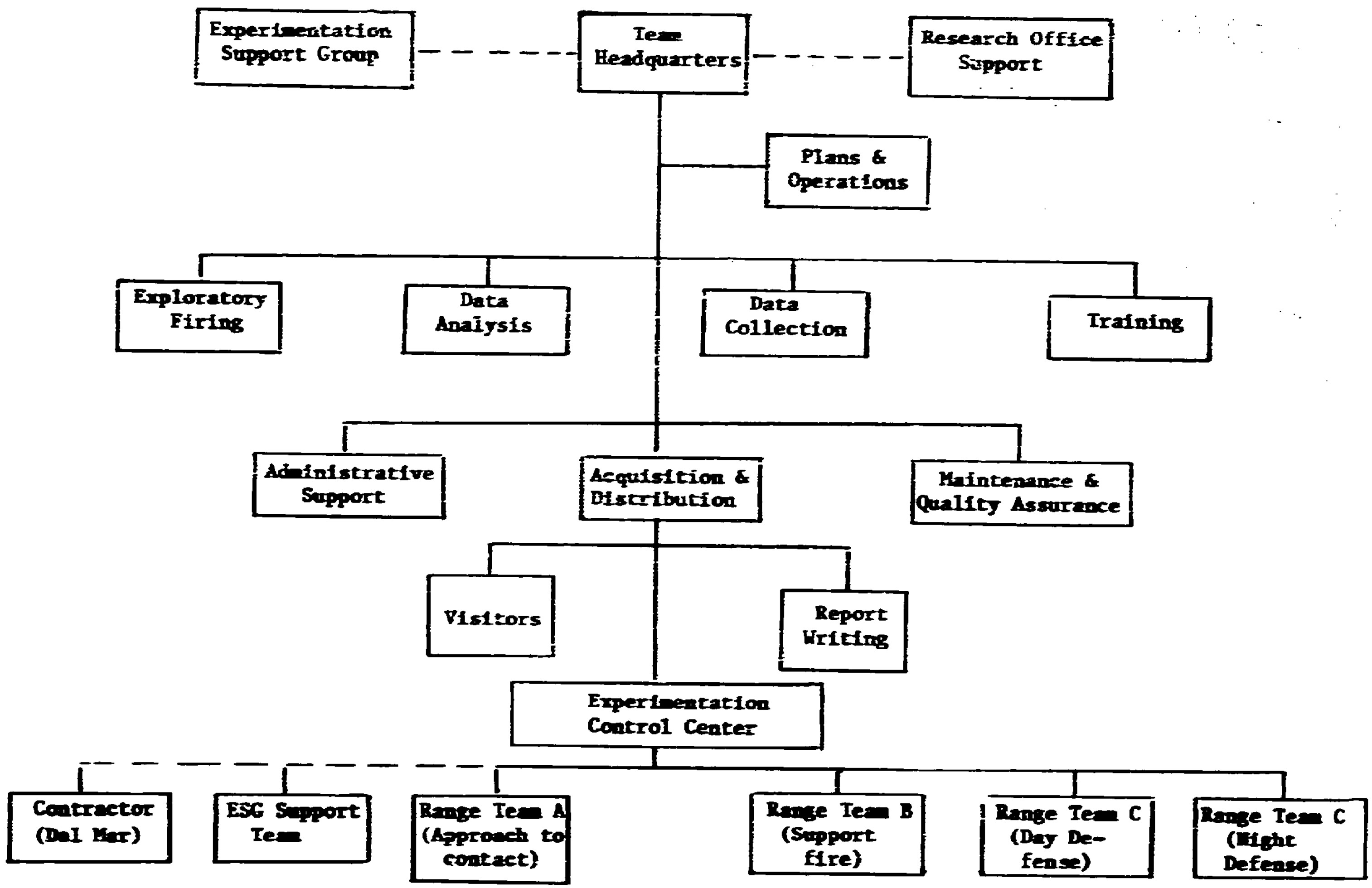
The team was interdisciplinary from its inception, with military and scientific counterparts teamed at all levels to balance military knowledge and scientific experimental expertise.

Major decisions were made, and the experiment was directed, by the project board consisting of the team chief, the deputy, and the project scientist. The board's decisions, with accompanying rationale, were recorded daily.

The team was flexible in size and structure; sections were formed and abolished in accord with the work schedule. See Figure IV-1 for the organization chart.

The Project Directive

The CDEC-SAWS directive was written by the project team, not by higher headquarters. After acceptance by the CDEC command it was coordinated with and approved by CDC. The directive served as the charter for further planning and implementation by the team chief. It included the particularly important instruction that the current family of Soviet small arms was to be compared with the U.S. weapons mentioned above. This was the first time a major test would compare directly the effectiveness of Soviet and U.S. weapons.



NOTE: Many of these groups were temporary, being added or detached as needed.

Figure IV-1. Organization of the CDEC-SAWS project.

The Project Analysis

The project analysis was a continuation of the analytical process that produced the project directive. The project analysis was an internal CDEC document that guided further planning and execution of the field experiment. An outline plan, a shorter version of the project analysis, was later submitted to CDC and approved. The project analysis and outline plan specified the following objectives:

- Devise quantitative effectiveness criteria by which rifle and machine gun squads armed with competing weapon systems can be compared under tactically realistic conditions.
- Provide experimental data for determining the combat effectiveness of the candidate weapons within an organizational and tactical context.
- Provide comparative data on the tactical consumption rates of ammunition and spare parts for the candidate weapons, to be used in cost-effectiveness studies (which, in fact, were later performed by Army headquarters and OSD).
- As a by-product of the training phase of the experiment, provide data on the relative ease with which soldiers can be trained to use the candidate weapons.
- Identify weapon characteristics that produce superior fire effectiveness within an experimental organizational and tactical context.

The project analysis specified that the weapons shown in Table IV-1 were to be tested.

These weapons were grouped into various candidate squad mixes, as shown in Table IV-2. The squad-weapon mixes were the subjects of the testing, not just the weapons themselves.

Resources

The project analysis specified a need for 1500 test subjects and support troops, three experimentation ranges, and about $1.8 million for outside procurement of hardware and support.

Table IV-1

WEAPONS TO BE TESTED

U.S. 7.6 mm	Colt 5.56 mm	Stoner 5.56 mm	Soviet Weapons
M14 rifle M14E2 automatic rifle* M60 bipod machine gun M60 tripod machine gun	M16E1 rifle (basically the same as the M16A1) Colt automatic rifle**	Stoner rifle Stoner automatic rifle Stoner bipod machine gun Stoner tripod machine gun	AK47 rifle (7.62 x 43 mm) RPD (squad-level) bipod machine gun (7.62 x 43 mm) DPM (cpmpany-level) bipod machine gun (7.62 x 54 mm)

*The straight stock, assault rifle version of the M14; about 8000 were produced.

**A heavy-barreled version of the M16 produced in prototype quantities only.

Table IV-2

WEAPON MIXES FOR CANDIDATE SQUADS

Type of Squad	Weapon Type: U.S. 7.62 mm	Colt 5.56 mm	Stoner 5.56 mm	Soviet 7.62 mm
Rifle	9 M14 rifles	9 M16E1 rifles	9 Stoner rifles	9 AK47 rifles
	9 M14E2 rifles			
	7 M14 rifles 2 M14E2 automatic rifles	7 M16E1 rifles 2 Colt automatic rifles	7 Stoner rifles 2 Stoner automatic rifles	
	5 M14 rifles 2 M60 bipod machine guns		7 Stoner rifles 2 Stoner bipod machine guns	
Machine gun	2 M60 bipod machine guns		2 Stoner bipod machine guns	(*)
	2 M60 tripod machine guns		2 Stoner tripod machine guns	

NOTE: Each filled square represents one candidate squad.

*Soviet machine guns could not be subjected to full-scale tests because too few weapons and too little ammunition were available.

These relatively large resource requirements produced a conflict within the CDEC because the two other active project teams placed legitimate demands on the same limited resources. This forced crucial decisions affecting the allocation of resources among experiments--decisions that were necessarily based on uncertain projections of anticipated results versus resources. After some controversy, the CDEC and CDC headquarters approved the resource requirements projected by the project analysis.

Basic Experimental Design

Concurrent with the development of the project analysis and the concept planning for the experimentation ranges, various aspects of experimental design were studied to determine the proper organizational level for testing. Machine gun and rifle squads were selected as the appropriate organizational level. Studies were then conducted to determine squad sizes, weapon mixes, and number of squads per weapon mix. Review of the reports of previous small arms tests and experiments provided little guidance because no previous small arms experiments had been conducted in a tactical setting using controlled experimental methods.

The decision regarding the number of squads per weapon mix was crucial because of the impact on the required number of men, weapons, equipment, and days of range time. If too few squads had been chosen, variations among squads could have invalidated the resulting comparisons of the candidate weapons. Nor did statistical analyses give a definitive answer. In the end, the decision to use six squads per weapon mix was based on the board's judgment and on the fact that six replicates of each firing situation permitted a balanced matrix of experimental conditions.

The decision to use a nine-man squad was based on the fact that, in combat, squads in any army are about this size or smaller. Organization of the squad into fire teams was rejected as unrepresentative of actual combat. Finally, 10 types of rifle squads having different weapon mixes and 4 types of machine gun squads were selected. The weapons they were assigned are shown in Table IV-2. The rifle squads that had machine guns were chosen to represent situations in which machine guns are attached to rifle squads, or to represent new infantry squad organizations that include both rifles and machine guns.

Instrumentation Requirements

The team prepared and provided to the CDEC Experimentation Support Group (ESG) its requirements for instrumentation to cover CDEC-SAWS targets and their simulators and electronics to control the targets and to measure the times of firings, hits, and near misses. The team derived the requirements from its own study of the state of the art of instrumentation. It revealed that existing, general-purpose equipment for small arms ranges was inadequate for measuring effectiveness. The team later furnished quantitative requirements to ESG as a basis for contracting the development of the instrumentation equipment.

The tight schedule of the experiment constrained the development and debugging of the instrumentation. ESG added CDEC-SAWS instrument requirements to an ongoing contract with Del Mar Engineering Laboratories to conserve time. Despite the constraints, the CDEC-SAWS project installed a small arms range system superior to previously available systems--mostly because the instrumentation was developed for a specific experiment using carefully conceived and well-defined effectiveness measurement criteria.

PREPARING FOR THE TEST

Exploratory Firing

The project board insisted on early and intensive exploratory firings because it understood the marked influence weapon firing doctrine would have on the relative effectiveness of the various weapons. It was assumed from the outset that the significant differences in muzzle impulse, configurations, mechanisms, and sights between the weapons could require a different "best" firing doctrine for each weapon type. The exploratory firings confirmed this assumption and showed that the firing techniques being taught for the M14 were not suitable for all the weapons.

An exploratory firing section, consisting of one officer and 27 enlisted men, was established to experimentally determine the best firing technique for each weapon and each firing situation. It did so by systematically varying such factors as burst size, ratio of ball to tracer, and aiming/pointing methods. The board reviewed the exploratory firing results

almost daily. Every decision regarding best firing doctrine (as well as any other issue affecting the design and conduct of the test) was recorded in decision memoranda to permit later review. See Appendix G for sample decision memoranda on firing doctrine.

Even though the main purpose of the exploratory firing section was to determine each weapon's best firing technique, it conducted many other supporting tests--some of an engineering nature. They included measurement of cook-off limits, cyclic rates of fire, ballistic performance, penetration, reliability of magazines and belt links, bench rest accuracy, and the effect of varying ammunition production characteristics.

Two particularly important tests were conducted. The first was to establish the safety of Stoner weapons, since Aberdeen Proving Ground had pronounced the weapons unsafe without the use of goggles (which could have seriously interfered with firing). The weapons were found to be safe without goggles. The second was to determine the major cause of the M16's high malfunction rate, which was correctly attributed to AMC's substitution of military-specification Ball propellant for the commercial IMR powder, for which the weapon had been designed. (Two years later, after serious problems were experienced with the M16 in combat in Vietnam, this finding was confirmed and acted upon--albeit by changing the composition of the Ball propellant and modifying the rifle's buffer to match the powder.)

Selection and Training of Test Personnel

Test Subjects

The test subjects were NCOs and privates drawn from the 194th Armored Brigade. They represented a mixture of backgrounds in armor, infantry, and artillery. Some had served in Korea; others were newly arrived from advanced individual training.

An interdisciplinary team of officers and scientists in the planning section compiled a sheet of complete data for each test subject, to be used in matching the squads. The squads were matched on the basis of previous marksmanship scores (and again after CDEC-SAWS marksmanship training), rank, branch of service, education, and time in service.

Combat experience was considered as a criterion but not used because of the difficulty of judging its quality and duration.

The subjects were segregated in barracks according to the weapon system to which they were assigned. Discussion of weapons by officers and NCOs was strictly forbidden, to eliminate the possibility of biasing the subjects' attitudes and motivation. Questionnaires were forbidden for the same reason.

Training of Test Subjects

An intensive training program was implemented to bring each group of test subjects to nearly equal proficiency in using their assigned weapon. It was particularly designed to eliminate a possible bias due to the subjects' prior experience with the M14.

In May 1965 the training section, headed by a lieutenant colonel, with one major, five captains, and five sergeants, was formed. They began by studying the available literature on small arms training methods. Concurrently, they were trained in the nonstandard weapons (Soviet and 5.56-mm) by project team members familiar with them. To minimize instructor variations, the training section prepared formal curricula and manuals for the training classes for each weapon. Instructors were trained through intensive review of the manuals and graded practice presentations.

At its peak the training section had about 350 cadre. One instructor and one assistant instructor were assigned for each five test subjects. About three weeks of training (compared with two weeks in normal Army basic training) were provided to bring subjects previously trained in the M14 up to full proficiency in the unfamiliar weapons. The training covered weapon functioning and characteristics, safety, assembly and disassembly, and individual marksmanship and squad firing on known-distance ranges. All subjects, including those assigned to standard Army weapons (the M14 and M60), received an identical amount of training.

The trained subjects were tested by a written multiple-choice test covering weapon characteristics, functions, and safety, by a timed disassembly and assembly exercise, and by marksmanship scores.

After completion of individual training, the test subjects were formed into squads and underwent "transition" training to familiarize them with unit firing against combat-type target arrays. For these tactical training unit firings, an attack, an assault, and a defense range were constructed. These were similar to the later experimentation ranges, though much simpler in instrumentation. Target cues were provided by M2 weapon simulators. The unit firings were also used to train range controllers and to refine safety measures.

Training of Armorer-Artificers

Fourteen armorer-artificers performed the normal armorer duties of weapon inspection and maintenance. They also diagnosed and recorded data on weapon malfunctions on the range. They were trained in a designated weapon system and then cross-trained in the other weapon systems to provide flexibility.

At Rock Island Arsenal, they were trained in weapon assembly, disassembly, operation, and functions and in diagnosing malfunctions. They also received instruction on the Stoner weapons from the designer, Eugene Stoner, and a representative of the manufacturer, the Cadillac Gage Company. Training on the Soviet weapons was conducted by CDEC-SAWS project personnel assisted by Fort Ord ordnance personnel.

The training stressed the development of skill in consistently identifying the true cause of weapon and ammunition malfunction. Detailed codes were devised and used by the armorers to record all malfunctions accurately and consistently. In the experimental firings, the armorers identified malfunctions and their causes on the spot. They were also instructed to save the defective parts and ammunition.

Handling of Weapons and Ammunition

Receipt

All test weapons were received, inspected, stored, maintained, and secured by the acquisition and distribution section, headed by a major who was a trained armorer-artificer. The same officer was also in charge of the armorers.

Upon receipt, all weapons and ammunition were weighed whole. They were then disassembled and each major part was weighed and inspected. Serial and lot numbers were verified against shipping documents and factory production records to prevent the introduction of specially produced weapons. The origin and representativeness of each weapon and each ammunition lot were carefully verified.*

Storage and Maintenance of Weapons

Weapons were stored in four van-type trailers for ease of transportation and security during the field experiment. The weapons were guarded at all times to prevent any possible tampering.

Maintenance of weapons was under the control of 1 officer, 4 NCOs, and the 14 armorer-artificers. Spare parts for the weapons were stored in three trucks used as weapon-repair shops.

For each weapon, data books were established to record by date and firing situation: (1) the amount of ammunition expended in each weapon and the burst sizes used, (2) any malfunctions, (3) the parts replaced in the weapon, (4) names of test subjects firing the weapon, and (5) zeroing data.

The cleaning of weapons was closely supervised by the armorer-artificers. Test subjects cleaned their weapons after each firing. Uniform cleaning procedures were enforced. The time the test subjects had with their weapons was controlled and kept constant to avoid biases.

Storage and Issue of Ammunition

Ammunition for the experiment was stored in the Fort Ord Ammunition Supply Point.

Three NCOs and 18 enlisted men operated the central facility where

*This precaution, though seemingly unimportant, was critical to achieving a representative sample of weapons. For lack of similar precautions, years of M14 testing at Fort Benning had been conducted with rifles specially selected and assembled by the producing arsenal; these rifles achieved shot group extreme spreads several times smaller than those of standard M14's.

magazines were loaded and ammunition issued. They loaded magazines by hand, lacking mechanical loaders. The ammunition was counted by two persons prior to loading. The use of a central magazine-loading facility allowed control and guarding of the magazines and the ammunition lots. Magazines not used during a day's firing were specially marked and used the next day to insure uniform treatment of magazines and uniform magazine spring compression time. Magazines identified as having caused a malfunction were removed from service and stored for examination.

Ammunition used in the experiment was identified and controlled by type, caliber, model, lot number, and manufacturer. Mixing of ammunition lots was avoided. Magazines delivered to the ranges were packed in ammunition crates and marked to designate the squad that was to use them, the experimental situation, date, caliber, type of ammunition, and lot number.

Machine gun ammunition was issued in metal link belts. The links initially received from AMC for the Stoner machine gun were manufactured under an AMC contract and differed significantly from the design specifications of the Cadillac Gage Company. These faulty links caused five to nine belt separations per 100-round belt. When the defect was discovered, the project team ordered 30,000 correctly made links from a private manufacturer; these links were used for the record runs. The limited number of links available required that the links be salvaged and reused, which somewhat degraded the reliability of the Stoner machine gun.

Range Design

Range design began with the planning section's compilation and review of the literature on small unit tactics and techniques in U.S., Communist bloc, NATO, and other armies. The review included combat reports, films, and unit journals from World War II and Korean War combat. Items of importance to the design of ranges and target arrays* such as the following were particularly noted:

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*See Appendixes D and F for summaries of combat information useful in range design.

- Range frequencies at which assaults were initiated.
- Range frequencies at which assaulting troops opened fire.
- Personnel and weapons other than assaulting troops that accompanied the assault (e.g., ammunition bearers, supporting machine guns, and other supporting elements).
- Assault formations.
- Speed of movement.
- Results of assaults.
- Range frequencies at which defenders opened fire.
- Disposition of defending elements.
- Supporting personnel and weapons and their location in the defensive position (e.g., forward observers and antitank weapons).
- Location of the defender's rifles and automatic weapons.
- Type of terrain selected for the defense.
- Lateral and vertical distances between foxholes.
- Exposure times of defending and attacking troops.

For the terrain over which the documented combat took place, the review also recorded terrain type, shape, dimensions, elevation, and cover and concealment provided.

Based on the combat experience of team members and the historical data, the varieties of small arms combat situations were analyzed to decide what basic situations to use for measuring effectiveness. They included defense, attack, approach to attack, exploitation, retrograde operations, night operations, security force actions, raids, and combat patrols.

Selection of Firing Situations

Typical platoon dispositions derived from the review were plotted to scale, using an overlay sheet of acetate for each country's army and each tactical situation. Every soldier (i.e., target element) within the platoon area was identified by location and body position (standing, kneeling, prone, or in a foxhole) as appropriate to his function in the array. Personnel such as an ammunition bearer, a forward observer, a radio

operator, a platoon leader, or a messenger, for example, would do little firing but would occasionally be more exposed than firers in order to accomplish their combat functions.

When superimposed, these overlays revealed the differences and similarities in tactics and techniques of the various armies. A synthesis of the similarities produced "normalized" target arrays that retained the elements of platoon disposition that were common to the doctrine of all major armies.

At this point, the wide variety of possible small arms situations had to be screened down to a manageable group of representative situations that could be simulated on a minimum number of different instrumented ranges. Situations that were tactically different but required similar firing conditions were merged.

Two moving attack situations were chosen, one a rifle squad assault against a prepared defense and the other a rifle squad advancing and encountering* small groups of enemy soldiers rising suddenly out of cover. (The latter also represented patrol-type situations.) For defensive situations, a day defense from foxholes and a night defense were chosen (day defense was also to be fired by machine gun squads). Two prone firing situations, a rifle squad acting as a base of fire (against the same defensive position used for the assault situation) and a rifle squad in support of an advance were also selected (both to be fired also by machine gun squads). These two situations represented fire support of attacking troops but could also be considered to represent long-range defensive fire support against enemy units in support of an enemy attack. Three generalized target arrays were sufficient to simulate these six basic situations: a range simulating infantry targets in defensive positions; one simulating attacking infantry; and one simulating small groups of infantry (such as patrols and outposts) that were neither attack nor defense postures but represented enemy encountered suddenly and unexpectedly. Table IV-3 summarizes the firing line and target array conditions for each of the planned tactical situations. (For detailed descriptions and drawings of each situation, see pp. IV-30ff.)

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*Referred to in CDEC-SAWS Main Text as the approach-to-contact situation.

Table IV-3

REPRESENTATIVE TACTICAL SITUATIONS FOR CDEC-SAWS TEST

Tactical Situation	Firing Line	Approximate Range (meters)	Target Array
Advance and encounter (rifle squad)	Squad advancing along parallel, twisting lanes.	20 to 150	Suddenly appearing small groups to either side and in front of advance lanes, generally visible as kneeling or standing and firing targets.
Base of fire for assault (rifle squad)	Stationary squad in prone positions.	250 to 350	Two squad-plus groups in foxhole defensive dispositions, targets mostly concealed, but target weapon simulations mostly visible and audible.
Base of fire for assault (machine gun squad)	Stationary squad in prone positions.	250 to 350	Two squad-plus groups in foxhole defensive dispositions, targets mostly concealed, but target weapon simulations mostly visible and audible.
Assault (rifle squad)	Squad advancing in assault formation (marching fire).	150 to 20	One of the above arrays.
Day defense against attack (rifle squad)	Squad in hasty foxholes (day).	350 to 40	Successive groups of standing targets, firing at closing ranges representing advance. Mostly visible.
Day defense against attack (machine gun squad)	Squad in hasty foxholes (day).	350 to 40	Successive groups of standing targets, firing at closing ranges representing advance. Mostly visible.
Night defense against attack (rifle squad)	Squad in hasty foxholes (night).	200 to 40	Successive groups of standing targets, firing at closing ranges representing advance. Mostly visible.
Support of advance (rifle squad)	Squad in prone position.	400 to 550	Two squad-plus groups kneeling, prone, or in foxholes in defensive positions; partially concealed and firing.
Support of advance (machine gun squad)	Squad in prone position.	450 to 750	Two squad-plus groups kneeling, prone, or in foxholes in defensive positions; partially concealed and firing.

Range Reconnaissance

After these situations and general target arrays were selected, final overlays were prepared to show each target by location, body position (standing, kneeling, prone, or in foxholes), required weapon simulator (if any), and approximate terrain desired. These overlays became the basis for a search for suitable terrain that would fit the drawings. This was contrary to most range design, where terrain is selected first and then target arrays are designed to fit the terrain available.

Members of the planning section used a helicopter to search for appropriate terrain within the boundaries of Camp Roberts, Hunter Liggett Military Reservation, and Fort Ord proper. The use of helicopters expedited the search, and large areas were rejected in a short time. Camp Roberts' terrain was too open and bare. Hunter Liggett had several possible sites, widely dispersed, but the hill sites were generally too mountainous and the open valley sites had too little ground cover. The search was finally narrowed to the Fort Ord property, where, after two weeks' search, suitable terrain was located for each range. This terrain provided appropriate relief and concealment around which to construct representative, realistic tactical situations. Of particular importance, it provided for target and firer positions consistent with the target range frequencies specified by the tactical overlays.

Range Organization and Construction

The next step was to organize the range field headquarters and to form the four range teams to construct and operate the ranges.

Organization of Field Headquarters

During the reconnaissance phase, a range team chief was assigned responsibility for constructing and then operating the ranges in accord with the plans. Later, an interdisciplinary experimentation control center (ECC), or field headquarters, evolved with four subsidiary range-control crews, one for each range plus one for night situations on the defense range. The ECC was assigned the following tasks:

- o Direct CDEC-SAWS range operations, including briefing, debriefing, and controlling the test squads; range security; and range logistics.
- o Preserve and protect range terrain, vegetation, instrumentation, and equipment.
- o Lay out and survey target and firing locations.
- o Construct the range.
- o Draft operating policies for the ranges and enforce them when approved.
- o Train the people who operate the ranges.
- o Maintain range instrumentation and equipment.

Key Range Personnel

For each range, a captain was designated range officer. He assembled an interdisciplinary crew to provide technical and scientific advice and administrative and logistic support. During actual firing runs, he was stationed in the range control tower. His decisions could be overridden only by the range team chief. On major decisions, the range officer routinely consulted his scientific counterpart, designated the range scientist. The range scientist provided advice (within the specified test plan) on the experimentation matrix, the validity of squad runs, and the validity of data resulting from the runs. During runs he was usually stationed in the computer van.

An instrumentation officer and a civilian engineer were assigned to each range crew to provide the range officer with immediate technical support. With the assistance of the range crew, they tested, calibrated, maintained, and replaced instrumentation and other range equipment. During runs, both were usually stationed in the computer van.

Five NCOs on each range crew had the primary task of assuring safety during firing runs. Designated controllers, they were selected from the best of the training instructors after the training of the test subjects. Having conducted the training and then having received additional safety training, the controllers were knowledgeable about weapon functioning and range safety. During firing runs, one controller was positioned

behind each three firers (but with strict instructions to neither interfere with nor distract the firers except when a safety threat arose).

Actual range construction work was performed by an ESG team, commanded by a major and under the general direction of the range team chief. The team began with 32 enlisted men, gradually increasing to 140 men (not including the diggers), 8 officers, and 6 civilian contract technicians. A heavy construction engineer platoon (1 officer and 37 enlisted men) was attached to the ESG team during July-October 1965. Besides constructing the actual ranges, the ESG team constructed exploratory firing ranges, communication networks, electrical power installations, fire-prevention facilities, and roads.

Preservation of Terrain

When the final range sites were approved, each range crew instituted measures for terrain preservation and security. Guards were posted and roads or potential entrances were blocked or controlled. Parking, personnel assembly, and smoking areas were established and marked; their use was enforced by the range officer. Work crews received formal instruction in terrain and vegetation preservation, fire prevention, and fire-fighting techniques. Strict "down range" discipline was instituted and enforced. Still and motion pictures were taken of the terrain and vegetation to establish the standard appearance as a guide for the range preservation repairs that continued throughout the firing runs.

Location of Target Arrays

The geographical center of each target array was first tentatively located in relation to the firing positions of the test squads, at the distances required by the tactical situation overlays. Next, the geographical centers of the target arrays were adjusted laterally and vertically until a balance was achieved between tactically realistic target dispositions and the desired target range frequencies.

Individual targets were located by spacing the lateral and vertical distances between targets while preserving the required overall width, depth, and vertical disposition of the target array. Locations were

marked with tent pins and were numbered. Soldiers were placed in the appropriate posture at each target location. The project board inspected each tentative array to determine the tactical realism of the dispositions and the intervisibility between targets and firers. After adjustments were made, the layout of each target array was approved by the board.

Each approved target location was marked with a standard silhouette target placed at the proper height, cant, and direction desired for the instrumented target body. This identified to the instrumentation contractor the exact orientation at which the instrumented target should be installed.

The advance and encounter situation presented particular problems in reconciling group firing safety, allowable safety fans,* and tactical realism. The solution was to lay out a twisting set of advance lanes marked with engineer tape. After much trial and error, target arrays were marked at the correct distances and within the allowable safety fans, using natural ground folds, depressions, and shallow gullies for concealing the instrumentation packages. Each firing position and target array combination was checked to insure that firers would not endanger other squad members. Targets were located at various ranges and angles from the advance lanes so as to give the firers the sensation of firing in different, unanticipated directions from the twisting path.

Target arrays on the day/night defense range had to be placed so as to represent a realistic platoon advance toward the defenders, and yet they had to remain hidden from view until raised. Realism was achieved primarily by taking advantage of natural folds, shallow gullies, and small washouts. During a subsequent heavy rain, these targets were flooded and damaged since they were all along natural drainage contours.

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*For the CDEC-SAWS weapons, the safety fan was an angular sector 8000 meters long with an additional 2000 meters of buffer zone on each of the three sides. The magnitude of the safety zone problem can be seen in the fact that each additional 45-deg turn in firing direction required an additional 16,000,000 square meters of land.

Land Survey

All firing positions and target locations were surveyed in detail by the supporting field artillery battalion's survey team, using a theodolite and measuring tapes. The location of each target and static firing position was established by grid coordinates and elevation from mean sea level. Firing distances and directions were computed using the grid coordinates.

Excavation

To avoid scarring the terrain around the targets, the ground was excavated by hand for the large instrumentation packages (wooden target-box "coffins" containing the target raising and lowering mechanism, target body, and near miss microphone) and the cable trenches between the target location, the control and recording van, and the junction boxes. Trenches were as long as 1000 meters. Approximately 21 soldiers per range were provided to excavate the advance and encounter range and the day/night defense range. The supporting fire range, which contained more targets and longer cable trenches, required 42 soldiers. Excavation and installation took about eight weeks.

Marked paths between targets for use by all range personnel were located along terrain folds, washes, and gullies to be invisible from the firing line. All personnel movement on the ranges was restricted to these paths to preserve the ground cover and appearance of the range and to eliminate any unwanted cues to target locations. Each digging outline for the coffins, cables, and junction boxes was carefully marked in three dimensions to ensure proper target orientation despite ground slopes and to shield the instruments from bullet impacts.

To provide motivation and to increase their understanding of the task, the diggers were given a short presentation covering the purpose of the ranges and the excavation. This included a firing-line view of the target arrays, a demonstration of the target mechanisms, the need to preserve ground cover, and the best digging method for minimizing damage to terrain and vegetation. The excavation was generally done by three-man teams, who were required always to remain within the outlined digging areas, literally

digging around themselves to avoid unnecessarily marking or damaging the surrounding terrain.

Firing Positions

The firing positions of the rifle and machine gun squads were arranged on the same tactical basis as that used for the target arrays. They were staggered in depth, consistent with tactical realism and safety. Thus they were placed with some vertical variation and were generally five meters apart laterally. The positions were constructed in accord with the scenarios devised for each tactical situation. Each set of firing positions was inspected by the board from the target areas, adjusted for tactical realism, and then approved.

The scenario for the day/night defense situation assumed that the defenders would have had four to eight hours' preparation time. Therefore, four- to five-foot hasty foxholes were dug with natural berms from the spoil. They were camouflaged with manzanita* brush, which provided the firer a realistic environment with some of the typical obstructions that would occur in combat. Sandbags, logs, concrete foxhole walls, and other materials that would not be available in combat within the time constraints, were not used.

For the base of fire and support of advance situations, the scenario assumed the attackers would have had at most an hour or two of preparation time. Therefore, only body impressions were scooped out, with a little manzanita brush for camouflage.

To avoid accidents from cook-offs with hot weapons, safety rules required cooling any weapon that had a chambered round before opening the chamber. To prevent immobilizing the range while waiting for the weapons to cool, cook-off pits (4 x 4 x 4 feet) were dug beside each firing line and at the assault termination point. The first cook-off occurred on the third day of experimentation.

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*Manzanita is a stiff, branching, smooth-leaved evergreen shrub. It is native to the Pacific coast of North America, where it forms dense thickets contributing to the harsh chaparral vegetation of arid areas.

Safety Fans

Range fans were determined for each situation in accord with standard Army requirements. Reconciling range safety with tactical realism, given the limited areas available, required extensive layout efforts.

Before siting the target arrays, targets, firing lines, and firing positions, a tentative range fan was calculated for the longest-shooting weapon.* Tentative firing positions and target sites were then plotted on maps or charts, which were overlaid with the safety fans to assess their consistency with range safety--a time-consuming process.

Safety fan limits were marked with red and white candy-stripe poles several hundred meters beyond the target arrays, so that the range officer and controllers could visually monitor safety. In addition, at each firing position, camouflaged rods to mark left and right limits were aligned with the candy-stripe poles. These rods were unobtrusive to the firer and the casual observer but provided an invaluable aid to the controllers behind the firing line, who knew the location of the rods in spite of the camouflage.

Emplacing Instrumentation Target Boxes

Target boxes were hand-carried along the marked paths and placed in the pits excavated for them. The boxes were then plumbed, and horizontal and vertical cant was corrected. Target height was verified by measurement. Sighting with binoculars from the firing positions ·sured that the targets were not inadvertently "covered" and that they presented the desired orientation to the firer. Previously excavated soil was brought in and poured around the target boxes until they were securely fixed in the ground.

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*Safety regulations require consideration of the maximum possible range of a projectile, which may be 5000-8000 meters beyond the maximum effective range of the weapon. A related problem was documenting, to the satisfaction of the range safety authorities, the maximum range of nonstandard or developmental weapons.

The Near-Miss "Halos"

Semicircular, wooden witness panels ("halos") six feet in diameter were used on the supporting fire range to sense near misses at distances where bullet speed fell below supersonic (since the microphones used for close targets could only sense the shock wave of supersonic bullets). When properly installed, the halos did not present unwanted visual cues, as had been feared. An expert engineer corps camouflage technician taught CDEC-SAWS personnel how to disguise the halos by appropriate camouflage installation and maintenance techniques. Strips of burlap camouflage material draped across the front of the halos broke up or distorted their flat surface. The telltale semicircular outline was eliminated with twigs of manzanita brush. Even the people who installed the camouflage later found it almost impossible to detect the halos from the firing positions.

Another problem arose with the three shock transducers--one for each of the three concentric near-miss zones of the halo--mounted on the halo frame to count near misses. Originally, the halo face was mounted on a metal frame. When struck by a bullet, it would transmit a ringing effect to the shock transducers, causing the transducer to sense as many as 100 near misses for one hit. The problem was corrected by converting to a wooden frame.

Administrative and Range Support Facilities

While the range was being constructed, the essential facilities required for range control, support, and administration were built. They included, for each range, a control tower 15-25 feet high, an observation platform, three tents for briefing, debriefing, and mess, a 20-foot house trailer for a visitors' office, and an administration/supply tent for the range officer.

The experimentation control center was centrally located and occupied two 30-foot house trailers for the command element and four tents for briefing, data collection, communications, and mess.

Road networks, parking areas, and hardstands were cleared and filled; 2543 five-ton dump-truck loads of fill dirt were used. In addition, 120 tons of rock salt were applied to the roads to lessen dust. During the rainy season a two-inch layer of beach sand was spread on the roads.

Exploratory Firing Ranges

Stringent time constraints forced exploratory firing (see p. IV-8) to coincide with development of the experimental design, the project analysis, and the early field trials. Four simplified firing ranges were quickly constructed at the beginning of the project to simulate four exploratory firing situations: assault, advance and encounter, day defense, and night defense.

The assault range consisted of two prepared lanes about 125 meters long, which ended at a standard, E-type cardboard silhouette target. An 8-foot-high, 24-foot-wide plywood backboard, with a replaceable cardboard facing, was placed immediately behind each target to capture near misses.

The advance and encounter range consisted of 16 standard M31A1 target-raising and -lowering mechanisms with E-type target silhouettes deployed in six discrete arrays. A machine gun simulator at each array cued the firers. Targets and their simulators were manually controlled at each firing point.

The day defense range consisted of six targets and backboards, somewhat similar to the assault targets but placed at various ranges up to 1250 meters.

The night defense range consisted of two oblique rows of E-type silhouette targets at distances of 25-100 meters. A machine gun simulator was located at the first and last target of each row to cue the firers. Lanes or positions were provided for motion and still photographers.

Communications

Commercial telephone service was provided to the range officer's administrative tent, the visitors' trailer, the data-recording van, and the experimentation control center. The control towers had direct lines to the range-control switchboard for use in emergencies.

The large volume of communication traffic necessary to operate and control the ranges dictated installation of a complete field wire net within each range and connecting each range with the ECC. Sixty-five telephone poles were installed, and 32 miles of field wire were laid.

To provide mobile range-control communications and a backup to the fixed communications, several separate radio nets were set up. They included an administrative net for the project team, a maintenance net, an emergency net for all control towers and the ECC, and an intra-range control net for each range.

Electrical Power

Light drops and outlets were installed to meet normal lighting needs. Approximately 6200 feet of #8- and #10-gauge wire were used. Range instrumentation was powered by two 208-volt, 3-phase standard Army generators. Belated discovery that the contractor's instrumentation was designed for 230-volt, single-phase equipment necessitated the installation of booster transformers to increase the generator's voltage to 230. As a result of this and the usual problems of generator stability, the experiment was hampered throughout by marginal and variable voltage. For instance, voltage was frequently insufficient to kick out the starting windings on the air conditioning motors for the computers, causing the motors to overheat. This did not affect the accuracy of the data collected, but it posed a serious maintenance problem.

Ammunition Control

A special table with nine bins, one for each firer, served as the point for issuing ammunition before the runs, and as the point for receiving and counting ammunition after the runs.

Fire Prevention

The ranges were on terrain covered with dense manzanita bushes, which caused a fire hazard because of dry weather and the continuous use of tracers. To preserve foliage, irreplaceable range equipment, and possibly lives, several exploratory meetings were held with the Fort Ord Fire Department and with the California and the U.S. Forestry Service. A detailed fire-protection plan was devised.

Approximately 35 tons of fire retardant (trade name Phoscheck) were sprayed on the three ranges by commercial crop-duster aircraft at three

separate times before and during the firing phase of the experiment. About 12,000 feet of 50-foot-wide firebreaks were bulldozed around the three ranges to isolate the untreated surrounding terrain. The Fort Ord Fire Department burned off about 1400 acres of ground adjacent to the ranges. All range maintenance personnel were trained in fighting electrical and brush fires by the Fort Ord Fire Department. Portable CO_2 and water fire extinguishers were placed in strategic locations throughout the range complex. Two 1000-gallon, pump-driven water tanks, mounted on trucks, were obtained and manned 24 hours a day.

Despite the many small fires ignited by tracers during the firings, less than four hours' aggregate time was lost because of fire; equipment loss was limited to a portion of one instrumentation box. Even more important, the critical vegetation cover for the targets was preserved. Its destruction would have invalidated the entire experiment.

Illumination for the Night Defense Situation

A site was leveled adjacent to the day/night defense range for installation of a truck-mounted, one million-candlepower searchlight, which was used to illuminate the firing line and the target array for control and data collection after each night run. It was also available for use in maintaining safety on the range whenever necessary.

Three other spotlights were fitted with infrared, covert-illumination filters, and each was positioned to light three firing positions. The controllers and the range officer could view the infrared-illuminated firers with either starlight scopes or night-driving binoculars.

Final Testing and Validation of Instrumentation

Because of tight schedules, the necessity for concurrent planning and design of the experiments, slippage of the instrumentation development schedule, and the contractor's inexperience, the system turned over to the project team in August 1965 was far from ready for valid firings for the record. In retrospect, it appears that about two months would be required for calibration and validation of equivalent instrumentation systems under normal time pressures.

The project team conducted a series of squad firing checks that disclosed several critical defects. Many targets would not go up or down when commanded. Some targets would receive multiple hits but none would be recorded. The acoustic near-miss sensors were not calibrated for the various types of ammunition planned for the tests. Weapon simulators did not always follow computer commands to start and cease firing, because of low propane and oxygen pressure; this caused nearby microphones to make false counts of near misses.

Project team personnel were eager to use the ranges for preliminary activities such as the following:

- o Testing the instrumentation in the tactical context.
- o Modifying and confirming the command program for the target arrays.
- o Giving practice to all personnel who would operate the ranges.
- o Confirming the best firing techniques for the various weapons.
- o Confirming the adequacy of safety measures.

On 23 September 1965, the team reported to CDEC headquarters that the ranges had still not demonstrated enough reliability to conduct valid test firings. The main problem was that most of the engineering calibration and validity tests had been conducted with artificial inputs rather than with live firings of the candidate weapons. The ESG instrumentation group disagreed, asserting that all instrumentation on the ranges was reliable enough to begin the experiments, though efforts to validate the instrumentation should continue. They argued that experimentation data could be corrected later for any bias.

Meanwhile, 975 trained and equipped test troops were standing by who could fire only once for the record on the instrumented ranges. The crucial question faced by CDEC headquarters and the project team was what <u>were</u> the acceptable instrumentation reliability and validity conditions under which the experiment proper could begin?

CDEC headquarters ultimately accepted the project team's assessment that instrumentation reliability and validity were unacceptable. Responsibility for validation was shifted from the instrumentation engineers to

the project team. A test and validation plan was drawn up. Extensive live firing trials to calibrate and validate hit counters, near-miss sensors, and weapon simulators were conducted. Numerous modifications to targets, sensors, and mechanisms were made before satisfactory results were achieved. In all, the experiment schedule slipped about two months because of instrumentation problems.

Target Command Programs

Computer programs had to be developed to command the appropriate target appearances, with their accompanying simulator firings, for each tactical situation represented. First, two groups of combat infantry officers in the planning section war-gamed the tactical situation on the actual terrain of each range. Next, through a sequence of successive approximations, each side developed its best and most probable attack or defense technique by assigning roles and counter roles to targets, simulators, and troops.

The resulting target and simulator timing instructions were then computer-programmed, taking into account the role of each target soldier, his likely exposure, and his appropriate firing patterns. These initial computer programs were used to drive each target array; the resulting target-exposure and simulator firing sequences were reviewed for visual and aural tactical realism. Modifying the initial programs to achieve the most realistic possible "battle tune" was a demanding, time-consuming process, requiring one month of full-time trial-and-error work by one officer and one programmer. Each tactical situation program had to be tuned and retuned to appear and sound like the initiation and buildup of fire in an actual firefight. Each target appearance had to be logically related to the function of the soldier represented and each simulator firing had to be logically related to its preceding target appearance. The "crescendo" of the fire had to convey the sound and feel of firefights that had actually been experienced in combat.

A second series of program modifications was initiated after observation of the exploratory squads firing against each tactical situation program. Introducing the firers necessitated some significant changes in the "battle tune" of the targets since a target's appearance and simulated

firings were halted whenever the target was hit. The resulting target command programs were observed by the board in firings with exploratory squads. After review and adjustment, they were approved.

The care and effort expended in fine-tuning the target command programs paid off in the realism achieved. Veterans of infantry combat firing the CDEC-SAWS ranges reported experiencing the eerie, tense feeling and stress of combat.

THE FINAL TACTICAL FIRING SITUATIONS

The planning, range construction, and target programming yielded nine tactical firing situations for testing the effectiveness of the candidate small arms. Six of the situations were for rifle squads and three were for machine gun squads. They are described below in range layout, firing line conditions, and sequences of target action. Topographical maps of each range and target array, based on the post-construction survey, illustrate the tactical situations.

Advance and Encounter

As a test rifle squad proceeded along the twisting advance lanes, 12 target arrays were presented, one at each of the firing lines shown in Figure IV-2. One to ten targets popped up as the squad passed each of these lines. (Arrows in the figure indicate which group of targets was presented for each firing position.) All targets were clearly visible, but instructions for distribution of fire did not permit all of them to be fired at by all nine firers in the squad. (For example, at the position where 10 targets were exposed, not more than three firers could fire at any one target--a necessary safety measure.) The targets were exposed from two to ten seconds each, with the longer exposures occurring only at the longer ranges (over 100 meters). As each group of targets appeared,* the firers had to shoulder their weapons (except for light machine guns,

*The appearances were not simultaneous at some firing positions; gaps of up to three seconds separated the appearances of the first and the last targets.

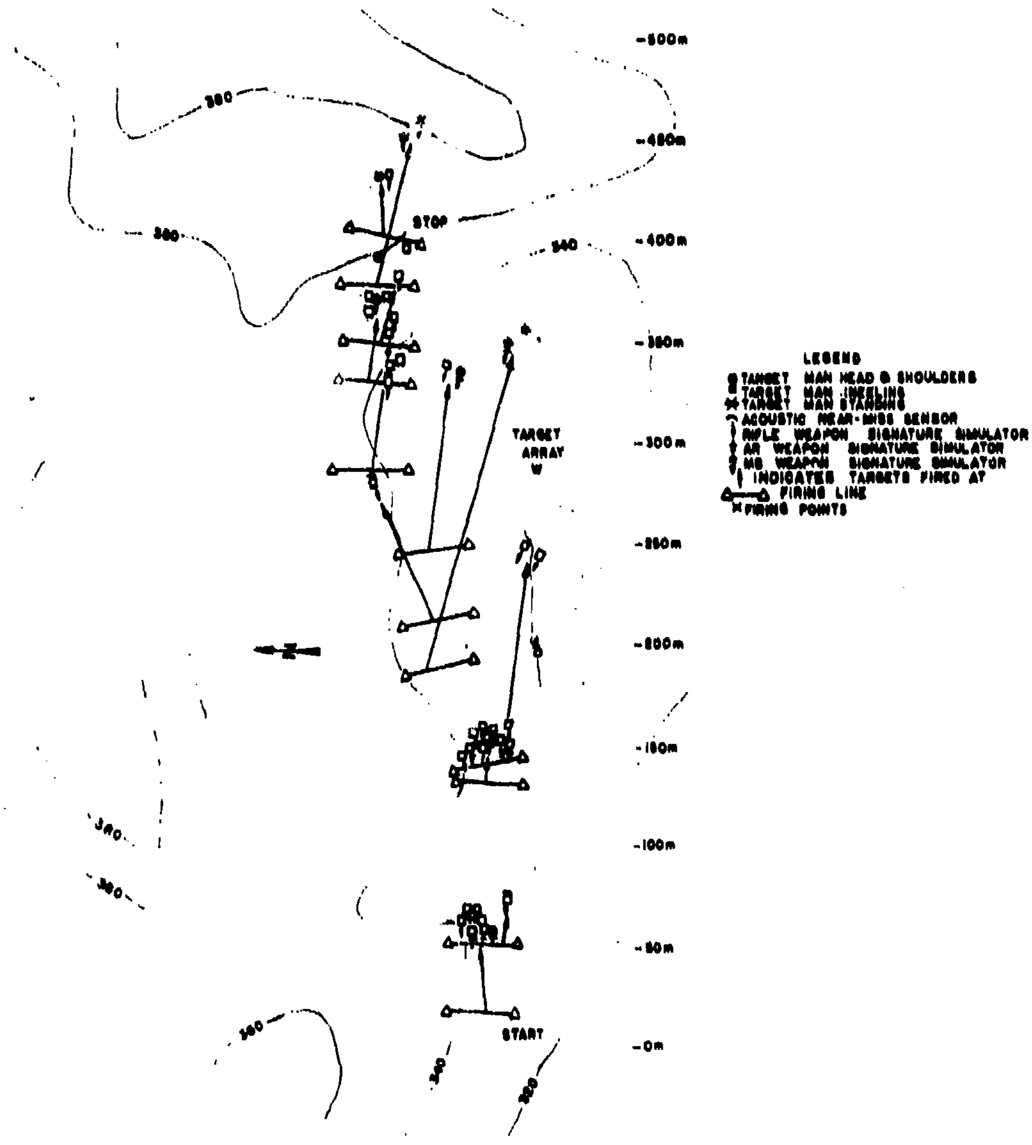

Figure IV-2. Range layout for advance and encounter (approach-to-contact) firing situation (rifle squad).
Adapted from CDEC-SAWS Annexes.

which were fired from an underarm position), and very quickly point and fire short bursts of automatic fire (unless their weapons permitted only semiautomatic fire). This combination of firing position, range, and targets tested the effectiveness of quick-reaction firing at visible, short-range, surprise target groups.

Base of Fire for Assault and Support of Advance

The base of fire situation represents a prone squad supporting an assault against prepared defenders in foxholes--the supported assault is the one tested in the assault situation described in the next section. The support of advance situation represents longer-range fire by a prone squad against an enemy squad that is providing supporting fire in the defense (and not fully dug in, as distinguished from the base of fire targets). These firing situations were tested on two portions of the supporting fire range (see Figures IV-3 and IV-4). Both rifle and machine gun squads fired at the target arrays (see Table IV-4).

Table IV-4

TARGET ARRAYS USED FOR BASE OF FIRE FOR ASSAULT AND SUPPORT OF ADVANCE SITUATIONS (Portrayed on Figures IV-3 and IV-4)

Situation	Designation of Array	Range to Targets (meters)
Base of fire for assault:		
Rifle and machine gun squads	Left, right	263-322
Support of advance:		
Rifle squad	X	389-434
	Y	488-545
Machine gun squad	Z	448-484
	X	613-645
	Y	690-753

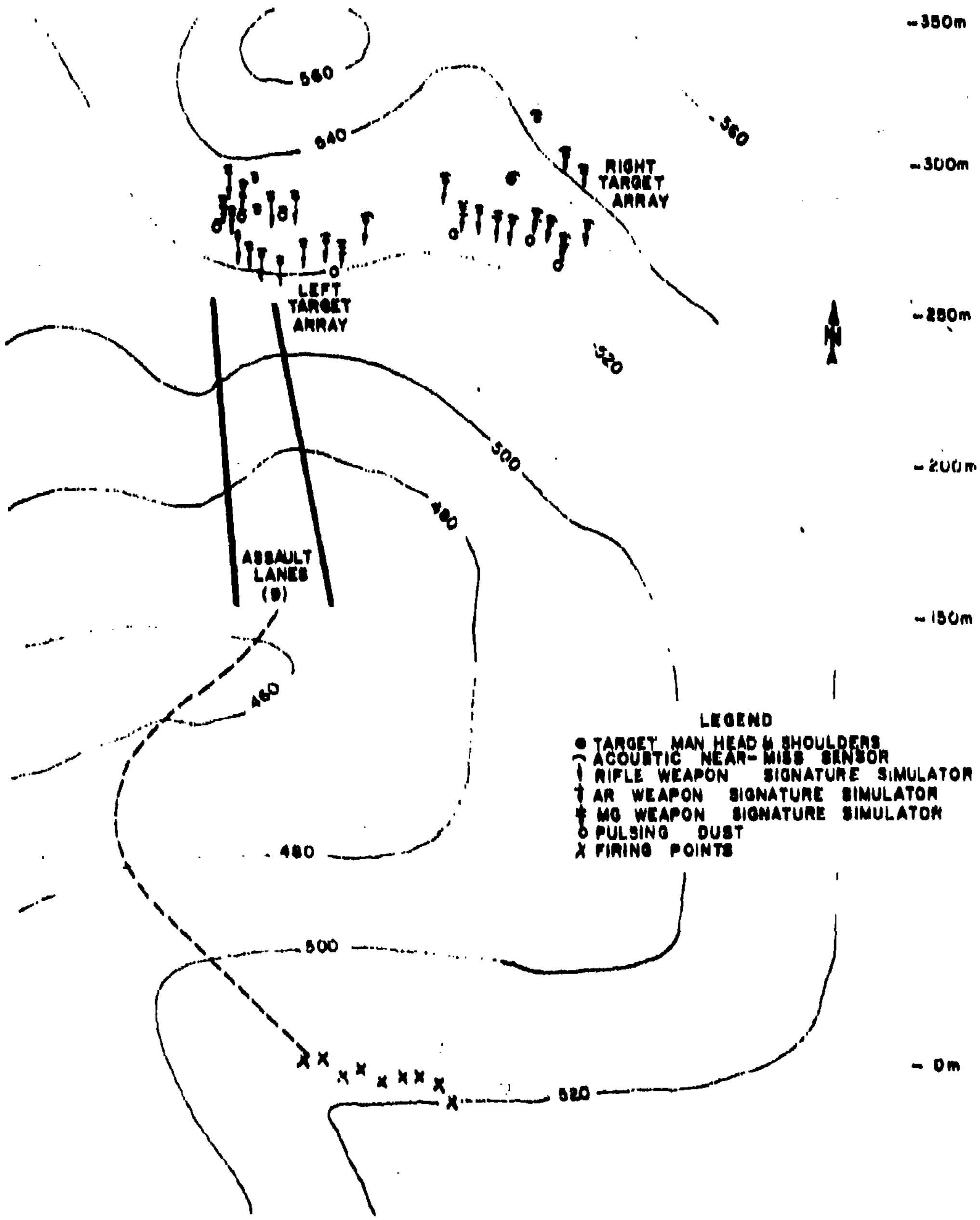

Figure IV-3. Range layout for assault (rifle squad) and base of fire against assault (rifle and machine gun squads) firing situations.
Adapted from CDEC-SAWS Annexes.

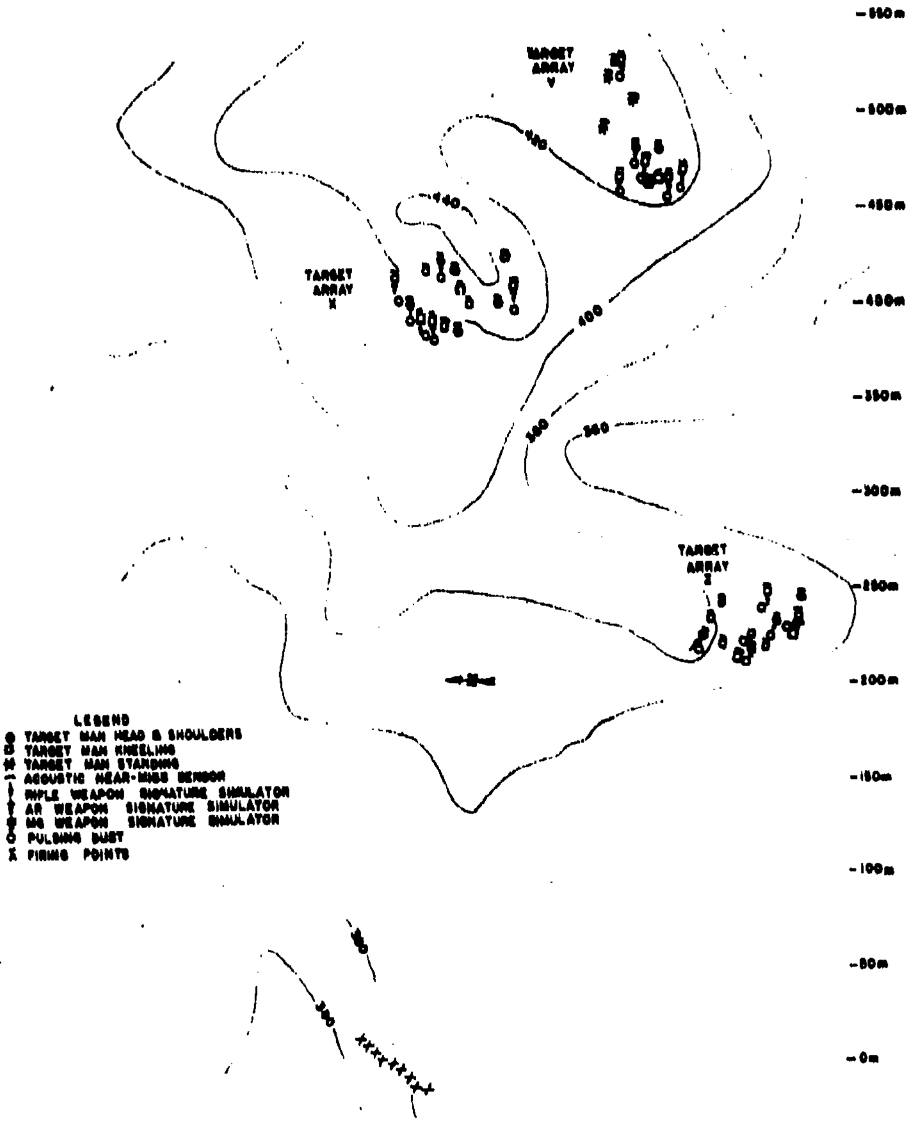

Figure IV-4. Range layout for support-of-advance firing situations (rifle and machine gun squads). Adapted from CDEC-SAWS Annexes.

The only differences in the firing situations for the rifle and machine gun squads were in the ranges from the firing points to the targets used in the support of advance situation (see Figure IV-4). The machine gun squads fired from a position (not shown on the figure) that was 240 meters farther away from the targets than the rifle squad firing line shown. Firers were prone in shallow depressions, representing hastily prepared firing positions. Few targets were visible, and those only partially so, but the locations of the firing targets were indicated by their visible weapon flash, smoke, and dust simulators. Targets popped up and the associated simulators built up their fire in a sequential pattern that exposed all targets by the end of about the first quarter of the allotted firing time. This time was two minutes for each array in the support of advance situations and four minutes for the combined left and right arrays in the base of fire situation.

These firing situations tested the squad's ability to rapidly distribute effective fire over typical defensive positions when using the target location cues normally available in similar combat situations. As is shown in the range layout figures, near-miss sensors were used on all targets.

Assaulting Rifle Squad

The assault fire situation was tested on the same range and against the same targets as the base of fire situation (see Figure IV-3). The squad advanced in line-abreast formation along individual assault lanes (i.e., between the heavy lines shown on the figure), firing every few steps at the target area. Firing procedures were similar to those used in the advance and encounter situation. Few, if any, of the targets themselves could actually be seen by the firers, but each target's weapon simulators produced detectable signatures. Targets popped up (and their simulators began to fire) in a sequential pattern that resulted in all targets being exposed by the time the firers had advanced a third of the way to the assault termination point (which was 15 meters in front of the nearest target).

The situation tested how rapidly an assaulting squad could bring effective fire to bear across dug-in defensive positions while walking forward. Near-miss sensors were used as well as target hit counters.

Rifle and Machine Gun Squads Defending Against Attackers

Both defense situations represented a defending squad, dug in on a hill, attempting to repel advancing defenders using marching fire. These firing situations were tested on the defense range shown in Figure IV-5. In the daytime firings the rifle and machine gun squads fired at identical targets from the same firing line. In the night defense firings only the rifle squad was tested; it used only the targets shown inside the area defined on the figure. Foxhole firing positions were used by all firers, and both semiautomatic fire and short bursts were tested.*

The most distant group of targets (representing the initial attacker formation) was exposed first, and all were potentially visible in daylight. None of the targets could be seen at night except when illuminated by tracers; however, target simulator firings were clearly visible at night. In daylight tests the longer-range targets remained exposed for 20 to 40 seconds. As the simulated enemy attack progressed and target groups were exposed at a range of less than 200 meters, the intervals between successive target group exposures became much shorter. Individual target exposure times for the successively closer groups also became shorter (5 to 15 seconds). Nearly half the targets were either invisible to half the firers or could not be engaged by them because of fire distribution instructions.

The climax of the simulated attack was the simultaneous exposure of the 10 closest targets to represent the initiation of the enemy assault on the firers' position. The whole process took eight minutes. The night tests simulated the last two minutes of the daylight tests (attack starting at about 120 meters) except for two major differences: target

*The exploratory firings yielded a new night firing doctrine for the automatic weapons: pointing fire with the head well above the sights and a 1:1 mix of ball to tracer to give at least one tracer round per burst. This gave improved pointing and better illumination. As a result of Vietnam small arms combat experience, this technique became part of the standard infantry battalion training curriculum.

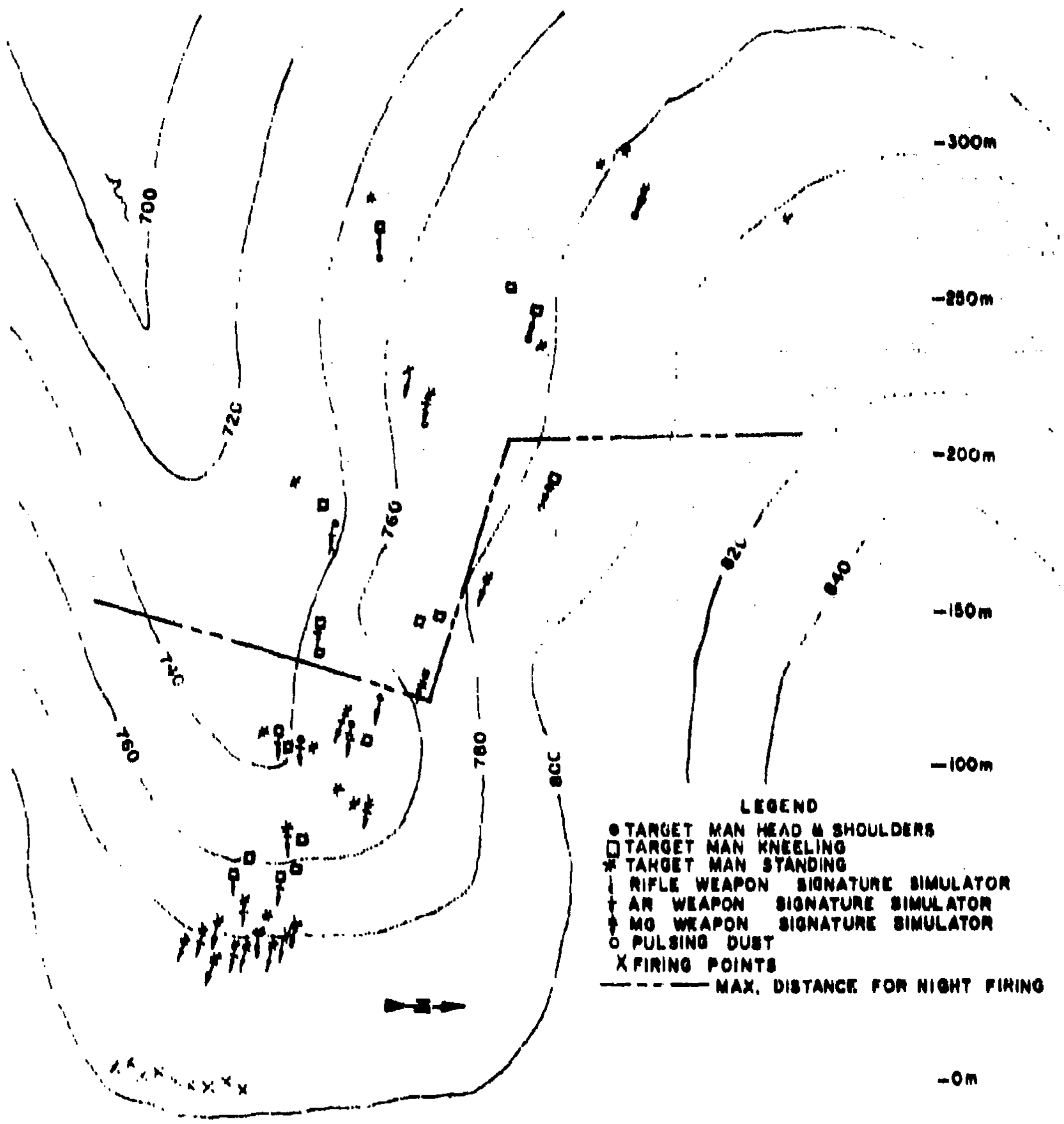

Figure IV-5. Range layout for day and night defense firing situations (rifle and machine gun squads). Adapted from CDEC-SAWS Annexes.

exposure times were just over half those in daylight, and a regrouping and reattack from shorter range (40 meters) followed the initial attack. The reattack included fewer targets and took longer; the two-cycle night "attack" provided for a total of almost five minutes of firing. No near-miss sensors were used; only hit counters recorded target effects.

The daylight situation tested how rapidly and effectively these squads could hit briefly exposed, visible stationary targets at successively closer ranges from prepared firing positions. The night situation tested how rapidly and effectively they could hit unseen targets at night in a similar situation (but over a shorter range spectrum) by using muzzle flashes as cues to target location, plus some tracer illumination.

EXECUTION OF THE CDEC-SAWS TEST FIRINGS

Squad Preparations

The test squads were normally picked up at their barracks by a project team member and their equipment inspected three hours before the time their test was scheduled to begin ("T" time). Then they were escorted to the weapon control vans in the rear staging area, where each squad member was issued his assigned weapon. During this time, radio and telephone contact was maintained between the rear staging area and the experimentation control center (ECC) to announce late changes in the schedule due to weather or instrumentation problems.

Once cleared by the ECC, the squad was escorted to the temporary holding area, where weapons and equipment were again inspected by ECC personnel. The squad remained in the holding area out of sight of the ranges until the preceding squad had left the range and it was declared ready for the next run. The ECC monitored the process over the range net.

Next, the range officer had the squad taken to the range, accompanied by a guide in radio contact with the range.

Squad Briefing

Upon arrival at the range, the squad placed their weapons in a rack outside the tactical briefing tent, which was out of sight of the range.

In the tent they were given administrative, safety, and tactical briefings by the range officer. The administrative briefing covered conduct on the range and the sequence of all squad operations and procedures. The safety and tactical briefing was given with the aid of a 4 x 6-foot, scaled sand table of the range showing the target arrays, firing positions, and range safety limits. The preprinted tactical briefing gave background information on the combat situation based on the scenario for the test firing situation. (As happens in combat, the test troops normally became quite tense at this point, and the tension increased until the run was over.) After the briefing, ammunition was issued at the nine speically constructed ammunition stalls.

The range officer then took the squad leader to a prearranged point overlooking the range and gave him a short, preprinted briefing of the tactical situation. The target array areas were specifically pointed out as possible areas of enemy activity. The squad leader then briefed the squad members, and they all moved into the firing positions.

Range Crew Preparations

The range crew reported to the range at 0530 hours to start the morning pre-run instrumentation test. It included running the target command program; verifying that targets and simulators functioned properly; checking the printout for spurious target hits or near misses; placing the dust boxes under the muzzles of certain simulators (to simulate pulsing dust from weapon muzzle blast); and doing other tests and calibrations as needed. The officer in charge of photographic data collection would brief each of the still and motion picture cameramen concerning the part of the firing situation he was to cover. This method assured systematic coverage of the significant aspects of each firing situation and weapon type.

Beginning the Run

The range officer would scan the range to assure himself that the range personnel were at their proper locations. He could determine this by the color-coded helmets they wore: for example, controllers wore yellow, firefighters wore red, and data collectors wore black helmets. On all

ranges except the defense range, personnel to make the manual hole counts and clean up the range after the run were positioned in armored personnel carriers in defilade positions to speed these post-run procedures.

If visibility was in question (Fort Ord is highly subject to fog), the range officer used a range pole at 1000 meters as a visual reference. No runs were conducted until visibility of that distance was achieved.

About five minutes before "T" time the range officer was given final clearance, through the radio/telephone operator, by the experimentation control center. Three minutes before "T" time control was switched to the computer console, where the display clock began the final countdown. If required, the range officer could override the system by command to the computer van. At "T" time the initial simulators and targets began the sequence.

Collection of Film Data During the Run

Manually operated 16-mm cameras and remotely controlled 16-mm gun cameras took motion pictures for monitoring and correction of incipient safety problems, for diagnosis of weapon malfunctions, and for documentation of firing techniques used. In addition, one cameraman on each range was assigned to record any unusual actions or reactions by the test subjects. Films were also used to determine whether the vegetation needed augmentation or repair to conform to the original appearance of the target array. One remotely controlled camera, located within the target array area on each range, provided a visual record of target effects.

Several slow-motion remote cameras were used to record test subjects' actions in the assault situation and the advance and encounter situation. They were located to one side of the path of movement and covered the firers as they approached the targets, providing a continuous record of the actions of men and weapons during a record run. The cameras were mounted on poles and were armored to prevent damage. Dummy camera positions were dispersed along the course to prevent cueing the firers to the location of event starting positions. Cameras were activated by an observer watching the firers.

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Posc-run Data Collection

After each run, two independent range crews counted the holes made in targets. In the debriefing area, each rifleman's remaining ammunition was counted; the reconciled counts were entered on data forms. Armorers inspected weapons and filled out malfunction reports. Observations on the conduct of the run were entered in a firing-run report. Three computer summaries of firing events, target events, and tuning of hits and near misses were printed out in the control van. A weather observation report was filled out at the weather station. Procedures for ensuring the accuracy and security of the collected data are described later in this chapter.

Planning the Next Day's Runs

At the end of each day, when the condition of range instrumentation could be projected for the next day, a meeting was held at the experimentation control center to plan the next day's runs. Participants were the range team chief, the project scientist, who was in charge of the scheduling matrix, and an officer from the planning section. "T" times were established for each run on each range for the following day. The "T" times were the basis of the schedule to check out the range and to control the flow of test squads, ammunition, and other equipment onto the ranges.

Handling Visitors

It was anticipated that the CDEC-SAWS experiment, being both novel and controversial, would attract many visitors of varying rank, prestige, and need-to-know. It was therefore thought necessary to provide for visitors in a way that would minimize interference with ongoing testing.

A visitors' section of the project team, consisting of one officer and three enlisted men, was formed to devise and carry out procedures for the control, briefing, and according of courtesies to visitors. A member of the section escorted each visitor, verified his access clearance before the range guard, and briefed him in an 18 x 18-foot observation platform off the range. Before the run the visitor would be taken to see the recording and data-control van and would be shown a color film depicting

the main elements of the experiment, to temper his interest in observing the actual testing.

REDUCING AND ANALYZING THE DATA

Data Reduction

Detailed planning was begun in August 1965 to provide for reduction and analysis of the data amassed from the experiment. Of prime importance were procedures to assure the control, accuracy, and security of the data collected from each run. The flow of data from input forms to final processing is shown in Figure IV-6. The project scientist headed the data-processing section, whose nucleus consisted of five mathematician soldiers in the Army's Scientific and Engineering Program. The range scientist and a data aide assigned to each range crew aggregated the manual counts of target hits and ammunition expenditure collected after each run. All manual hit and ammunition counts were done by two independent crews; differences in the two sets of counts were reconciled by recounting.

Computer-recorded data on firing events and target events (e.g., hits and near misses) were recorded on magnetic tape, and run-by-run summaries were produced by each range computer.

The manually collected data on hits and ammunition expenditure were transferred to large data sheets, totaled, and analyzed for variability and reliability. Weapon malfunction data recorded by the armorer-artificers were collated and analyzed, as were meteorological observations of rainfall, visibility, wind speed and direction, and light intensity for the night range. The meteorological data proved useful in accounting for variations in the long-range firing results. The differences in computer-recorded (i.e., from firing-line microphones) and manual counts of ammunition expenditure were adjusted by proportionally apportioning the rounds not counted by the computer along the time curve of those that were counted. A similar adjustment was made for differences between manual and computer-recorded hit counts.

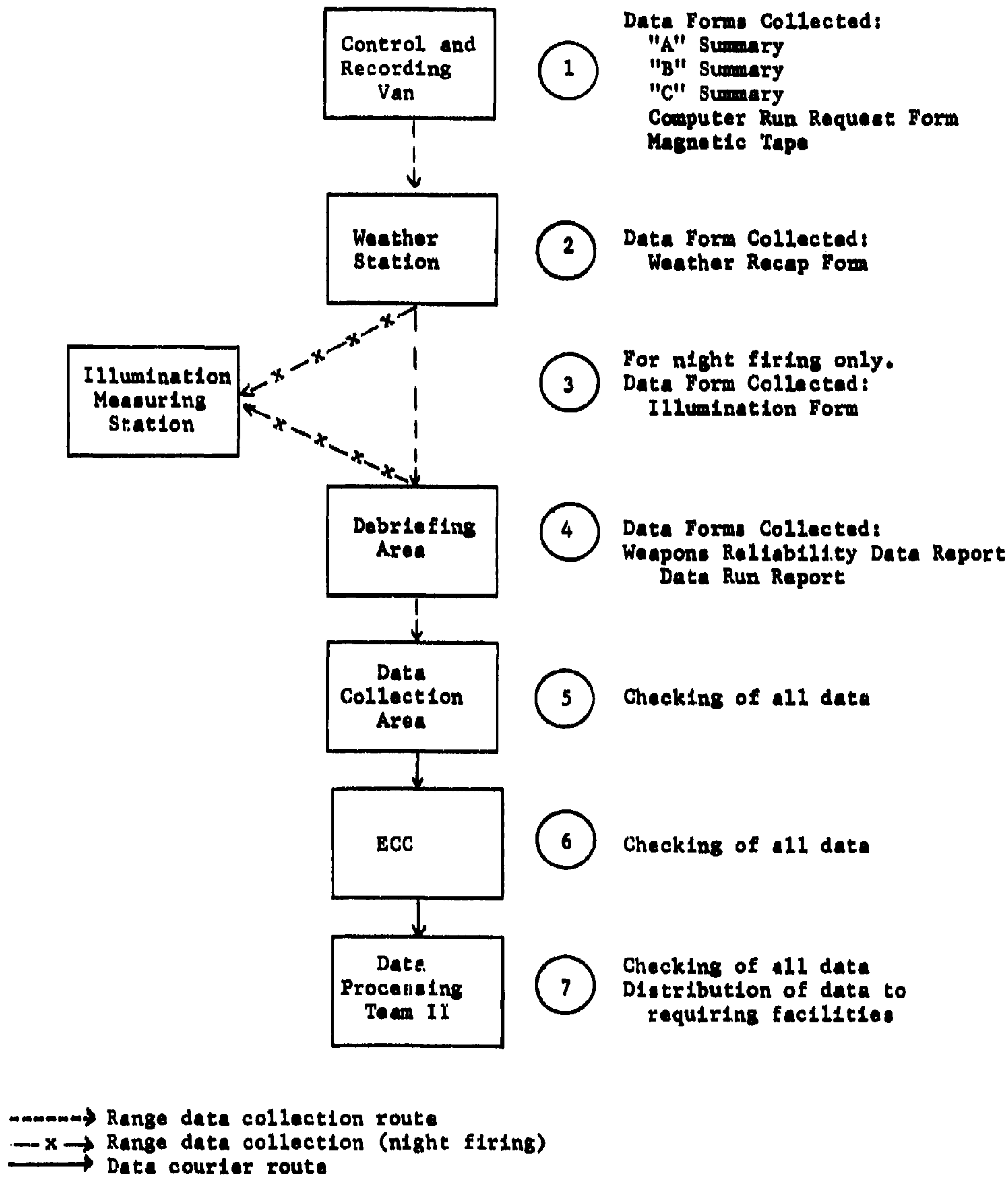

Figure IV-6. Processing of CDEC-SAWS data.

Data Analysis

Statistical analyses of the data were performed by the project scientist, working with SRI personnel. The analyses were coordinated and reviewed by the project board. The final comparisons of the weapons tested were assessed by the board.

As determined early in the experiment, the major measures of effectiveness for comparing the weapons were the following:

1. Cumulative exposure time (CET) in target-minutes, to represent effectiveness in hitting exposed targets rapidly.
2. Total number of near misses on the target array, to represent suppressive effects.
3. Percent of ammunition remaining, to represent sustainability.

Subsidiary measures were also taken and compared to help explain the results obtained for the major measures of effectiveness; they included number of targets hit, total hits,* and rounds fired.

For each firing situation, the results achieved by the various weapon mixes in the major measures of effectiveness were compared. First, the results for each measure and each situation were averaged across all squads firing the same weapon mix. Then the statistical significance of each paired comparison (measure of effectiveness-weapon mix) for each situation was calculated using standard Gaussian techniques.

The board made a series of aggregated comparisons using various weightings for each firing situation to determine whether overall rankings of the weapon mixes were sensitive to the weightings used. Because results proved insensitive to the weightings, only the results for equal weighting were shown in the final report; however, the situation-by-situation results were given so that readers could perform their own weighting.

Subsidiary analyses were performed and described in the published results. They included the learning effect for squads refiring the same

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*Even though targets fell when hit, multiple hits could be achieved while the target was falling.

range, measures of "engineering" accuracy for the various weapons, and comparisons of reliability.

Several important effects on variations between the squads were observed but not analyzed; they included the following:

- The performance of the best squads appeared to depend heavily on certain individuals, who not only achieved high rates of hit but also, by firing early and accurately, drew the fire of their fellow squad members to the right part of the target array. The unusual importance of this effect in increasing the combat effectiveness of squads prompted the board to recommend conducting follow-up experiments to determine the feasibility of identifying these "best" firers and their effects. CDEC did not pursue the recommendation.
- Perhaps the single largest environmental effect observed was time of day or sun angle. A change of sun angle could greatly increase or decrease the difficulty of detecting targets, producing large differences in firing results.

Wound Ballistics Analysis

Wound ballistic testing was not an explicit part of the CDEC-SAWS experiment, but the terminal effects of weapons and ammunition were studied and considered during all phases of the experiment. Early in the planning a comprehensive literature search was conducted and a bibliography compiled on the subject. Study of these materials helped the experiment's designers take into account the likely impact of terminal effects on weapon effectiveness comparisons.

The relative terminal effects of the various weapons tested were suggested in the high-speed films of the target arrays showing differences in exploding sandbags or splintering brush and halo frames.

A separate supplement to the CDEC-SAWS final report was published that reviewed and analyzed the wound ballistics information gathered.

Reporting the Experiment

The necessity of concurrent operations delayed report planning until officers were released from the training and planning section in September 1965. The section had been led by a lieutenant colonel and, at its peak, was staffed with ten officers and several enlisted men.

The officers were assigned to write descriptions, prepare final tabulations, and do the editing. Because of the late start and the accumulating masses of material, writing the report rapidly turned into a 24-hour-a-day operation. To save time and ensure consistency of style and approach, the actual writing was done by the team chief. Owing to the comprehensiveness of the data and the detailed analysis intended, it was possible to produce only an interim report by the CDC-imposed suspense date of 31 January 1966. To forestall a lengthy in-house review by CDEC, the project board regularly briefed CDEC's commander and principal staff on the progress of the analysis of the results. The board similarly briefed the CDC staff.

The final report was published in May 1966. It included such important details as scaled maps of the target arrays, time sequences for the command program for each target array, intervisibility measurements, reliability results, descriptions of the engineering tests for accuracy and malfunctions, detailed data on the weight of weapons and ammunition, and comparisons of the statistical significance of the averaged measures of effectiveness for each weapon mix and each firing situation.

Chapter V

CURRENT FACILITIES AND EQUIPMENT FOR TESTING SMALL ARMS EFFECTIVENESS

This chapter describes and assesses the facilities and equipment available for conducting effectiveness testing of small arms at the U.S. Army Combat Developments Experimentation Command (CDEC), Hunter Liggett Military Reservation, California, and at the U.S. Army Infantry Board, Fort Benning, Georgia. First the chapter describes the instrumentation system on the test range complexes and compares their technical performance. Then it describes the range layouts and firing situations on each complex and assesses their suitability for testing the effectiveness of small arms. New equipment, now used neither by CDEC nor the Infantry Board, that might be useful in small arms field experiments, is identified. Where possible, costs for equipment and facility operations are estimated.

BACKGROUND

The early development of ranges for testing small arms is closely associated with the development of ranges for training. For many years, small arms tests were conducted on "known-distance" (KD) marksmanship and "transition" ranges similar to those used in training. The former provided measures of accuracy in slow fire at bull's-eyes as a function of range and firing position; the latter measured accuracy in rapid fire against silhouettes.

The measures typically used were quite different from the measures of effectiveness defined in Chapter III. For instance, on KD ranges, weighted hits (weighted by the score for each ring of the bull's-eye) and extreme spread in a group of 5 to 10 shots were the typical measures. On transition ranges, the total hits measure was usually used, with an element of time pressure introduced by exposing targets for brief periods.

These types of ranges and measures were used for both rifle marksmanship and for testing weapons.*

In the mid-1950s, operations research studies suggested that the measures of effectiveness derived from KD or transition ranges did not provide an adequate basis for evaluating the combat effectiveness of competing small arms.** These studies recommended that better measurement criteria be devised and equipment be developed that would:

- o Better simulate combat conditions.
- o Accurately record hits and shots fired as a function of time (the necessity of measuring near misses was not yet recognized).
- o Permit the precise reproducibility of target system events from run to run.

Such range "system" equipment first appeared in the 1956 SALVO I and the 1958 SALVO II field experiments.*** The SALVO I target system, designed and built by the Electronic Laboratory of the Johns Hopkins University Research Office, had the following features:

- o Stationary targets that could be raised and lowered on command from a central point.
- o Moving targets that could be raised, moved along a track, and lowered on command.

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*With minor variations, such ranges and measures were used in service tests throughout the 1950s. The T48 and T44 rifle tests are examples.

**Johns Hopkins University, Operations Research Office, Operational Requirements for an Infantry Hand Weapon, by Norman A. Hitchman, statistical analsyis by Scott Forbush and George Blakemore, Jr., Technical Memorandum ORO-T-160, AD 000-346 (Chevy Chase, MD, 19 June 1952).

***Johns Hopkins University, Operations Research Office, Tactics Division, SALVO I: Rifle Field Experiment, by Leon Feldman et al., Technical Memorandum ORO-T-378, AD 304-321 (Bethesda, MD, June 1959); Johns Hopkins University, Operations Research Office, Tactics Division, SALVO II: Rifle Field Experiment, by Leon Feldman et al., Technical Memorandum ORO-T-397, AD 325-385 (Bethesda, MD, May 1961).

- Target skins in the shape of size E and size F silhouettes* that would record the instant of bullet hits so accurately that trigger pulls and hits could be matched when several firers were firing at the same target.
- Devices attached to weapons to count shots fired with the same timing accuracy. (These devices limited testing to stationary firing lines and may have interfered somewhat with weapon firing.)
- Weapon simulators that approximated the sound and flash of small arms fire.
- Paper tape recording of all target system events.
- Paper tape programming of target system events such as targets up or down and simulated fire.

The SALVO I experimenters were thus able to investigate individual firer hits as a function of time, distance, target exposure time, firing position, weapon type, time of day, and firer proficiency. The experiments were limited to firings from stationary firing lines. Although firings were conducted by squad-size groups, the target array only simulated briefly and randomly exposed individual targets, rather than tactically deployed infantry units. The target instrumentation was unreliable--targets sometimes failed to go up or down--and somewhat inaccurate. In particular, the SALVO I hit skins gave inaccurate counts, and, although holes were counted manually, enough data were missed to impair the validity of the results.

SALVO II, conducted about a year and a half after SALVO I, had an improved target system that solved most of the main reliability problems. Thus, the SALVO II results were considerably more consistent and valid than SALVO I results. The experiment provided important insights and inputs to subsequent small arms effectiveness testing.

Between the 1958 SALVO and the 1965 CDEC-SAWS tests, little work was done on small arms range instrumentation. In the mid-1950s, a new target

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*F targets (head and shoulders) have an area of 2.38 sq ft; E targets, 4.59 sq ft.

pop-up device was developed as part of the Army TRAINFIRE ranges to make small arms training more efficient and realistic. However, aside from the introduction of mechanical pop-up targets in training, no further SALVO-type target systems were developed or used until 1965. As a result, when the SAWS field experiment was assigned to CDEC, little off-the-shelf equipment was available.

The CDEC-SAWS tests made several demands on instrumentation not made by the SALVO tests. First, the test design required measurement of near misses to evaluate suppressive fire effects. Second, tactical firing situations were defined as integral parts of two-sided engagement scenarios; thus, moving firing lines would be necessary in some of the situations. Finally, the CDEC-SAWS test prohibited any instrumentation that required modification of the weapon or the attachment of wires to either the weapon or the firer.

Two other CDEC-SAWS instrumentation improvements were the more realistic simulation of small arms enemy fire with spark-ignited, propane-fueled weapon simulators (as opposed to SALVO's blasting caps) and the more efficient computer recording of target system data (as opposed to SALVO's multi-channel pen recorders).

In one matter--the time accuracy of shot and hit recording--the CDEC-SAWS requirements were not as stringent as those of SALVO. The SALVO test required precise time records to match shots and hits, since the test was designed to obtain individual firer scores in the squad firing situation. In contrast, CDEC-SAWS used aggregated squad results as the basic effectiveness measures, so it was not essential to match shots and hits.*

The CDEC-SAWS target system design did not include targets that moved in addition to popping up and down. The SAWS tactical situations required targets advancing toward the firers while following terrain contours. Because existing moving target simulators only followed level,

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*The CDEC-SAWS project team considered requiring instrumentation of sufficient time accuracy to obtain individual firer results. However, it was decided that individual scores would not improve the basic measurement of effectiveness enough to justify the extra development time and cost and the extra risk that the resulting equipment would interfere with the firer.

straight tracks, a complex, new moving target mechanism would have to have been developed for CDEC-SAWS. Rather than incur the cost and risk of this development, it was decided that the sequential appearance of groups of stationary pop-up targets at successively closer ranges would provide the desired moving attack simulation.

After the SAWS test, CDEC began work on the Infantry Rifle Unit Study (IRUS) operational tests, assigned to CDEC in 1966. Because of the demands made on the Fort Ord terrain by the Infantry Training Center, the SAWS instrumentation was moved from Fort Ord and reinstalled in a different configuration at the Hunter Liggett Military Reservation (HLMR). However, the new installation did not follow the carefully developed SAWS process of tactical situation synthesis, terrain selection, on-site target-firer gaming, and final "battle-tuning."

The CDEC-HLMR small arms ranges are still in operation and are one of the two major facilities available for conducting small arms field experiments. Among the several experiments that have been conducted on the CDEC-HLMR ranges are the IRUS tests (completed in 1968),* and the 1972 operational test comparing the M16E1 and the XM19 (flechette) rifles.** The ranges are now being used for Force Development Test and Evaluation (FDTE) experiments investigating rifle fire techniques and prototype equipment. The proponent agency for these tests is TRADOC.

In the late 1960s CDEC had plans to replace these ranges with an advanced target system featuring self-contained target units that would not require the use of buried cabling. A contract was awarded for the design and construction of this advanced system but was later ruled in default.

The second major facility that is available for the conduct of small arms field experiments, the Infantry Board system at Fort Benning, Georgia,

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*U.S. Army Combat Developments Command, Infantry Rifle Unit Study 1970-1975 (IRUS-75), Phase I, AD 870-281L (Ft. Ord, CA, August 1967).

**U.S. Army Combat Developments Command, Experimentation Command, XM19 Serial Flechette Rifle Experiment (21.9) (U) (Short Title: USACDEC Experiment 21.9 (U)), 4 vols., ACN 13105, AD 521-235L, 521-236L, 521-237L, 521-659L (Ft. Ord, CA, June-July 1972), Confidential/NOFORN, hereafter cited as CDEC Experiment 21.9.

is an outgrowth of the CDEC-SAWS instrumentation. In 1965, through an agreement between the President of the Infantry Board and the Commander of CDEC, arrangements were made to transfer the technology of the SAWS target system to the Infantry Board. The project analysis* conducted by the Stanford Research Institute to identify the Infantry Board's needs concluded that the Infantry Board instrumentation should perform essentially the same functions as the CDEC-SAWS and SALVO ranges, including measuring individual firer scores. The hardware system that eventually resulted differs significantly from the CDEC-SAWS equipment, in part because it was developed later and over a much longer period (1965 to 1970). The range layouts of the two systems differ even more, as will be seen.

CDEC AND INFANTRY BOARD INSTRUMENTATION

This section describes and compares the equipment used on the CDEC and Infantry Board ranges. The description traces the systems from targets and sensors to control and data recording.

Pop-up Targets

Pop-up targets consist of two main elements: a raising and lowering device and a target body. The target body serves both as a visual cue and a hit sensing device when raised and visible; when raised but concealed from the firer, it serves only as a hit sensing device.

CDEC and the Infantry Board both use the same raising and lowering device, the M31 TRAINFIRE target mechanism procured through the Navy Training Devices Center and manufactured in the early 1960s by the BNF Manufacturing Company and the Joanell Engineering Laboratories. These are no longer in production, and spare parts are hard to obtain.**

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*U.S. Army Infantry Board, Project Analysis-Small Arms Test Facilities and Methods, prepared by Stanford Research Institute (Ft. Benning, GA, May 1965), hereafter cited as USAIB Project Analysis, 1965.

**At the time of publication, it was learned that Rock Island Arsenal has let a contract to Fourdee, Inc., Casselberry, Florida, to manufacture 1000 of the M31A1 target mechanisms.

CDEC and the Infantry Board use quite different target bodies. The CDEC target body is three-dimensional and comes in two sizes: a head-and-shoulder size having a head-on presented area of 1.64 sq ft and an upper-torso size having a presented area of 3.27 sq ft.* A target body is made from stamped aluminum covered with a layer of foam rubber. A piezo-electric transducer is attached to the bottom of the target. The target body records a hit when a projectile penetrates the foam rubber and imparts a shock via the aluminum to the piezo-electric transducer. The foam rubber has two functions: it tends to prevent the recording of hits by slow projectiles that do not penetrate the foam rubber, and it tends to dampen the shock reverberation caused by a penetration, preventing the recording of multiple hits after only one penetration.

The Infantry Board range uses an upper-torso target body that consists of a two-dimensional silhouette with an exposed area of 3.27 sq ft. It is made of plywood faced with three layers of foam rubber separated by two layers of tempered (brittle) window screening. The two layers of screening are electrically charged so that when the target is penetrated a "hit" signal is produced by the momentary contact of the bullet across the two conducting screens.

There are significant differences in cost between the two types of targets. There appear to be differences in capability, but no side-by-side tests have been done. The CDEC target can record rifle hits--and, it is claimed, fragment hits--from 360°.** The Infantry Board target, being two-dimensional, is useful primarily for recording rifle hits from the front. The Infantry Board target records rifle hits more accurately, in theory, because a positive penetration is required before a hit can be registered. Piezo-electric transducers may score hits without a penetration, or may score occasional multiple hits from a single hit, due to vibrations. As regards cost, the CDEC target body costs about $95 and

*Another full-torso target with a presented area of 5.5 sq ft is available from the manufacturer but is no longer used by CDEC.

**This permits testing of grenades on the same target systems as rifles.

can record a total of about 100 hits before needing replacement. The Infantry Board's target body costs about $4.00 and can score up to 100 hits per square foot before needing replacement.

Both types of targets are claimed to be highly reliable in detecting hits and in discriminating against lesser damage, e.g., small stones thrown against the target by close bullet strikes. No results of validation tests have been published, however. The Infantry Board target bodies are manufactured by Joanell Engineering Laboratories, Livingston, New Jersey, and the CDEC targets by Del Mar Engineering Laboratories, Los Angeles, California.

Moving Targets

The existing moving targets move on a straight, level track and can be raised and lowered on command. They consist of four main elements--a target raising and lowering mechanism, a target body, a track and propulsion mechanism, and a data link for transmitting hit signals. Both CDEC and the Infantry Board have moving targets using the M31 pop-up mechanism and the standard target bodies. CDEC uses a small cart on rails, driven by a somewhat noisy Volkswagen engine. The Infantry Board uses a platform on standard conveyor tracks driven by an electric motor. CDEC's is a special-purpose mechanism fabricated in-house. The Infantry Board's moving target system is manufactured by the Saratoga Conveyor Company, Atlanta, Georgia, and is available on order from the manufacturer. It appears to be considerably more useful and reliable than that used by CDEC. The last element of these moving targets, the data link, is discussed on p. V-11.

Weapon Simulators

Both CDEC and the Infantry Board use the same propane/oxygen small arms fire simulator, a unit manufactured by Joanell Engineering Laboratories. The simulator can be programmed for single-shot or burst fire. The CDEC devices have been modified so that they can accurately reproduce the pulsing dust raised by muzzle blast. These devices have demonstrated good reliability. The Infantry Board detonates TNT blocks to simulate

artillery and mortar fire on some of the ranges; CDEC does not. (TNT explosions do not realistically simulate the effect of artillery fire on riflemen; they simply add another source of uncontrolled variation to the test firing situations.)

Near-Miss Recording

CDEC and the Infantry Board have different equipment for recording near misses. CDEC only uses near-miss measurement occasionally; the Infantry Board has published no test results using near-miss scoring.

CDEC uses a microphone emplaced just in front of the target to measure the amplitude of the bullet shock. This is then translated into bullet miss distance by comparison with amplitudes recorded in controlled firings conducted at each target location. The Infantry Board uses four microphones placed in a row in front of the target, two on each side at distances of 5 and 7 feet. The shock's arrival time is measured at each microphone; these times are used to triangulate the location of the bullet as it passes over the row. Neither method will work when bullet velocity falls below 1100 feet per second (which occurs at 800-900 m range for NATO 7.62 mm and at 500-600 m for M193 5.56 mm*), but measurements beyond these distances are of little or no interest in simulating small arms combat firing conditions.

In theory, the Infantry Board method is much more accurate than the CDEC method. Accuracies of ±3 inches in x and y coordinates have been measured in tests where the system was precisely adjusted and the bullet passed perpendicularly to the row of microphones. For the CDEC method, accuracies of ±1 ft have been recorded under ideal conditions.**

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*Julian S. Hatcher, Hatcher's Notebook, 3d ed. (Harrisburg, PA, Stackpole, 1962).

**Litton Systems, Inc., Mellonics Systems Development Division, Infantry Weapons Test Methodology Study Quick-Fire Experiment I; Final Report, by Ronald D. Klein, Contract DAEA 18-68-C-0004, prepared for United States Army Infantry Board, USAIB Project 3091, AD 914-686 (Ft. Benning, GA, 27 June 1969), p. 80, hereafter cited as USAIB Quick-Fire Experiment I. The measurements are made by comparing bullet strikes on targets with strike positions predicted from microphone data.

Because the CDEC method measures shock amplitude, it is quite sensitive to the bullet type, the bullet velocity (and therefore range), and the shape and acoustic properties of the ground near the target. This makes extensive firings essential for initial calibration of each target and sensor; frequent recalibration is also necessary. Because the CDEC method uses a constant shock amplitude as the near miss criterion, the resulting near miss zone is not semicircular but instead has long "tails" near the ground, where the shock is reinforced by ground reflection. This may not be undesirable since a soldier's perception of near misses may be more closely related to shock amplitude than to the absolute miss distance of the bullet's trajectory.*

In contrast, it is claimed that the Infantry Board system needs no calibration. However, the four microphones involved have to be positioned very precisely; therefore, it seems likely that frequent measurements and checks, if not strictly speaking calibration, are probably necessary.

The CDEC system has had little experience measuring miss distance since the IRUS tests of 1967-1968. The measures of effectiveness that were defined for later operational tests did not include suppressive effects or involve flechettes, on which neither the CDEC nor the Infantry Board system could make reliable measurements.** The Infantry Board miss distance system has never been used--apparently because the Board has no interest in measuring suppression effectiveness for service tests.

The cost of the Infantry Board system is essentially the cost of four microphones, at about $60 each. The CDEC system includes one microphone and some signal conditioning circuitry for data transmission to the computer (see below). This would probably not be required for a system built today.

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*Because of the importance of suppression effectiveness, thorough testing of near miss perception is badly needed. Little or nothing is known on this subject a present (see also the footnote, p. V-15).

**A test of miss distance measurement for flechettes was conducted by USAIB, but no formal report was published. The shock wave was so weak that it could not be detected at distances greater than 5 ft. As a result, the Infantry Board microphones could not record flechette miss distances. Similar difficulties can be expected using the CDEC method to measure flechette miss distances.

Data Transmission, Power, and Control

Both CDEC and the Infantry Board primarily use buried wires to transmit data (e.g., hits, misses, target up or down status, simulator firing confirmation*), control instructions, and power.

The CDEC system transmits firing data in two stages: from the target/simulator or sensor data source to a signal conditioning unit near the target, and from there back to the central computer. Control commands are transmitted in the reverse direction along separate wires. The signal conditioning components are housed in large, buried wooden boxes (see Appendix F, Figure F-5). Control and data signals are transmitted by 30-lead telephone cable. The Infantry Board system was designed to transmit directly to the computer with one coaxial cable running from the target to the central computer for each data collection point. For instance, a target that has a miss-distance indicator will have six coaxial cables--one for each of four microphones, one for the target hit signal, and one for the target up or down signal. In addition, control commands are sent through a twisted pair of field wires for each target and for each weapon simulator.

Power is provided to each target and weapon simulator by buried cable. The Infantry Board uses #6 three-wire power cable with power provided by a 30 kW generator; CDEC uses commercial power with cable of about the same capacity.

The Infantry Board devices for recording shots fired (discussed below) and the moving targets transmit their data by radio, as do the CDEC moving targets.

The main difference in data transmission between CDEC and the Infantry Board is that the Board has eliminated the signal conditioning units used at CDEC. This saves the cost of some relatively simple electronic components installed down range but requires heavier, shielded transmission wire due to the absence of signal preamplification. Both systems have

*The CDEC system provides a signal separate from the firing signal to confirm that the simulator has fired; the Infantry Board system does not.

demonstrated adequate reliability in data transmission except for the perennial problem of small animals chewing through buried wires.

Recording Shots Fired

It is important that the recording of shots fired not interfere with the firer when he fires his weapon or when he moves from point to point. It is also important that the collection of these data not change the firing characteristics of the weapon. Both the Infantry Board and CDEC now violate this prohibition to some extent.

CDEC uses a shot counter installed in a special stock for the M16.* Presumably, any other weapon to be tested would have to be modified in the same way to be tested on the CDEC ranges. The shot counter, hence the weapon, is wired to a special transmitter helmet in moving situations. For stationary firing, it is attached to a light wire connected to a buried cable on the firing line.

The Infantry Board shots-fired counter for stationary situations is a microphone mounted near the firing positions. For moving situations, a counter is used that is self-contained and mounted on a standard helmet liner. It uses two sensors to avoid recording the firings of adjacent shooters; the first senses infrared radiation of the muzzle flash and turns on the second, which senses the sound of the muzzle blast. The second pulse is then transmitted via a small, helmet-mounted radio link. The helmet liner and counter weighs the same as a regulation helmet but has most of its weight forward (see Appendix F, Figure F-6). No tests have been conducted to determine how this special helmet may influence a soldier's firing performance.

The main problems with the shot-counting devices used by CDEC and the Infantry Board are their reliability and their potential interference with the firer and his weapon. Microphones on the firing line have demonstrated good reliability and fair accuracy, but they cannot be used in situations where the firer's firing positions are not known in advance; they are also

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*For stationary firing, the shots-fired counter (a firing line microphone) described in Chapter IV is still available. However, in recent experiments CDEC has used the equipment described here.

somewhat unreliable in discriminating adjacent firers. The Infantry Board helmet-mounted shot counter (which appears to interfere less than special stocks wired to a helmet transmitter) is unreliable at certain sun angles and occasionally records the firings of adjacent weapons up to 16 ft away. A less important constraint of this system is that it can record only eight firers because it is limited to eight separate transmitting channels.

Data Recording and Control

Equipment to record data and control the target array is van-mounted and adjacent to each range. At CDEC, the van includes an SDS model 910 computer, a magnetic tape unit, a teletype, and interface equipment. The Infantry Board system has a PDP 15/30 computer with about the same peripheral equipment. Both are relatively easy to program. Both print out raw data and summaries in forms that can be readily used to monitor ongoing firings and to perform later analyses. The Infantry Board computer is six to seven years newer than the CDEC computer. Thus, the Infantry Board computer has more capability (e.g., multiprocessing, faster turnaround) and has a much faster internal clock rate. This rate is fast enough to permit the matching of shots fired with hits and near misses, thus allowing an assessment of individual performance within the squad. The matching is performed by a Board-developed program that is run after each firing trial. Firers are given their scores after each trial, as an incentive to better performance.* When analyzing results, the Board always statistically aggregates the individual scores to make weapon comparisons. No analysis of the effects of individuals on squad performance, or of interactions between firers, has been performed.

The Infantry Board computer van is used to control several ranges by being moved from one range to another; at CDEC, one van is used for each range.

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*Because the firers compare overall hits performed, this has the adverse effect of creating an unrealistic emphasis on careful, slow aiming at the expense of achieving as many hits as possible as quickly as possible.

Safety

Although safety procedures should vary as a function of how the ranges are used, safety protocols tend to become permanent fixtures of range operations. Both the CDEC and Infantry Board ranges have reduced the safety problems inherent in range operations to the point where they are almost as safe as ordinary training ranges, though at some cost in realism. Range fan limits are well marked; stationary firing lines, as well as firing lines and lanes for moving situations, are prepared and marked. In moving situations on the Infantry Board ranges, every four firers are accompanied by a controller who tells them when to fire and insures that they stay in line. Films taken during the IRUS and XM19 tests on the CDEC range show even increased safety precautions--a controller accompanied and physically restrained each firer.

Photographic Coverage

Both the Infantry Board and CDEC customarily use photographic coverage for documentation and reporting. The emphasis and extent of coverage varies widely from test to test.

Weather

Both the Infantry Board and CDEC customarily make routine measurements of wind and precipitation conditions during firing trials. There is no indication that these data are used in the analysis of results, although such use is certainly feasible. In certain Infantry Board tests, target contrast has been measured and related to scores, with inconclusive results (probably because contrast is too simple an optical measure to predict difficulty of detection). Visibility and incident light are not routinely measured.

GENERAL ASSESSMENT OF THE TECHNICAL PERFORMANCE OF THE CDEC AND INFANTRY BOARD RANGES

As would be expected, the long development period and the almost continuous use of the Infantry Board ranges has resulted in equipment that is significantly more reliable and more economical to operate than the

CDEC range. The equipment is better than CDEC's in rapid data reduction, reliability of moving targets, cost and accuracy of targets and hit counters, and timing accuracy for shots, hits, and near misses.

There are two main ways in which both systems are deficient. The first is the counting of shots fired, where neither range has a completely satisfactory method. The second deficiency is in near-miss measurement: both systems only record rounds that pass the target.* As was noted in Chapter III, near misses that strike the ground in front or to the side of the target are important, both because they are noticeable and because different automatic weapons may have significantly different upward biases in their miss distributions.

A somewhat less important deficiency of both systems is their reliance on buried wires for data, control signals, and power transmission. This requires continuing maintenance to repair damage to wires by small animals; requires some disturbance of the terrain during installation or changes; and makes it difficult to change the range to generate new and unfamiliar situations. The Infantry Board system requires less down-range equipment and fewer holes for large, CDEC-type target "coffins." On the other hand, the Board system requires five coaxial cables, a power cable, and a twisted pair control wire to a typical target site. This means that a trench must be dug and commercial wire ploughs cannot be used.

One alternative to present methods is the use of a single power cable that superimposes multichannel, multiplex signals on the power transmitted. This reduces wire-laying effort at the cost of adding a standard multiplex processor at each target. Another alternative is telemetering data and control signals and the use of battery power at each target. The penalties of such wireless range systems include the extra complexity and unreliability of radio transmitters and receivers and the need to replace or recharge batteries frequently. In return, the need to dig wire trenches

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*The initial Infantry Board instrumentation included wide, low (8 inches high) strips of the target body hit-sensing material, hidden in front of each target to record near-miss impacts forward of the target. These strips were abandoned because they increased target maintenance and the Board showed no interest in measuring suppression effectiveness.

is eliminated, but the ease of shifting targets will still be limited by the need to protect and bury the target equipment boxes and the extensive amount of planning and "tuning" essential to producing adequately realistic target arrays. On balance, the switch from buried wires to telemetry hardly seems worth the risk and cost.

RANGE LAYOUT AND FIRING SITUATIONS ON THE CDEC AND INFANTRY BOARD RANGES

Range Layout

As background to describing the CDEC and Infantry Board ranges, it is useful to review briefly the layout of their predecessors, the SALVO and CDEC-SAWS ranges.

SALVO represented a new approach to range layout, being based largely on a questionnaire survey administered to World War II and Korean War combat infantrymen. Thus, the SALVO target system represented the target range frequencies and exposure times reported by this group. Subsequent use of the target system indicated deficiencies in the estimates of target exposure times; however, it was the first attempt to objectively relate target arrays to the combat environment.

The aim of CDEC-SAWS range design was to devise a range layout that would permit measuring the effectiveness of various rifle and machine gun squads engaging typical enemy infantry small units. Special attention was paid to the tactical realism of the nature, visibility, and deployment of the targets presented. The tactics and actions of both sides in each simulated combat situation were studied; based on this study, target exposures and simulated target firings were timed as they would be in combat.

The Infantry Board's aims were somewhat different. They wished to improve the firing ranges and firing measurements used in small arms service tests. A secondary aim was to conduct service tests as efficiently and quickly as possible. The main measures of effectiveness preferred by the Board were total hits and hits per round--for individual firers, not squads--as a function of distance and firing position. These measures were to be obtained in firings against a standard set of targets, intended

to represent combat-type targets.* Neither SALVO's attempt to simulate distributions of target exposure times and distances nor the considerably more complex CDEC-SAWS simulation of two-sided small unit combat was attempted in the Board's range layout.

Two features of the Infantry Board range illustrate this. First, weapon simulators are used not to simulate realistic firing by individual targets but to cue firers to the general target area. The simulators are not placed directly under each target that has a firing function, as in CDEC-SAWS. Instead, one or two simulators are usually placed behind each target group. Second, all targets are visible to the firers on the Infantry Board range. Apparently this approach was adopted in the belief that firing at concealed targets was not a fair test of a weapon's accuracy. A secondary consideration may have been the belief that visible targets lead to higher hit percentages, which, in theory, would require less time to achieve statistically significant results.

The Infantry Board range was designed to test several firers at once (except on the quick-fire course, because of safety constraints) in order to improve the efficiency of service testing. This should not be interpreted as an attempt to simulate squad firings, although Board test planners do not object to the realism that adjacent firers add to the firing situation. Instead, multiple firers are used as an efficient means of collecting a large sample of individual scores in a short time.

In contrast, the aims underlying the CDEC range layout at HLMR are not a matter of record and thus can only be inferred. The CDEC-HLMR layout was designed for the Infantry Rifle Unit Study tests, which were intended to assist in determining the most effective weapon mix (e.g., rifles, machine guns, and grenade launchers) for small infantry units. This purpose does not imply ranges radically different in concept from CDEC-SAWS. However, a comparison of the two range layouts shows wide differences. There is little vegetation and no target concealment on the current CDEC-HLMR ranges. The targets are placed in widely separated groups that do not represent target distributions and weapon cues similar to CDEC-SAWS.

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*USAIB Project Analysis, 1965.

The moving targets are unrealistic "shooting gallery" targets presented on a separate moving target range.* The target event programs do not represent combat actions; instead, they resemble the Infantry Board practice of presenting randomly grouped and individual pop-up targets at various ranges.

CDEC-HLMR Firing Situations

Assault Fire

Assault fire is conducted against an array consisting of 17 targets randomly located in a rectangle 50 meters wide and 25 meters deep. The array is located 106 meters from the initial assault positions and up a bare,** gentle slope with high ground to the rear. The target positions can be seen before the targets are raised, and most have nearby automatic rifle or machine gun simulators. Five firers can fire at one time. Firing is conducted while the firers close from 106 meters to 36 meters from the target.

Firing at the Same Targets from Different Firing Points

Five target groups consisting of six or seven targets and weapon simulators in each group are arranged so that they can be fired at from successively closer, prepared firing positions. The target groups are located on bare, gentle slopes slightly higher than the firing positions and at ranges varying from 111 to 220 meters.

Firing at Targets from Longer Ranges

Five groups of targets and simulators are located 210 to 574 meters from a stationary firing line. These groups have 5 to 15 targets and simulators; they are located on slightly higher ground than the firing line, with little or no vegetation.

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*The moving targets were added in 1972 to accommodate a test design forwarded to CDEC from the Infantry Agency, Ft. Benning, Georgia, that specified the use of moving targets (CDEC Experiment 21.9).

**In both the CDEC and Infantry Board descriptions this means bare dirt or short grass.

Firing at Targets Appearing at Successively Closer Ranges

Four target groups consisting of five to seven targets in each group appear at progressively decreasing ranges of 300, 200, and 50 meters from a stationary firing line. Again, these target groups are slightly higher than the firing line and are on a gentle, bare upslope.

Infantry Board Firing Situations

Assault Fire

Ten pop-up targets are located in an evenly spaced row up a bare, gentle slope from initial assault positions 88 meters away. Two weapon simulators are placed behind the row. Behind them is one laterally moving pop-up target. Four firers can fire at these targets as they close in from 88 meters to 33 meters.

Firing at the Same Targets from Different Firing Points

Four firers move from 360 meters to 88 meters, firing (upon the controller's instructions or from successively closer prepared positions) at the same ten targets as above. The slope of the ground is slightly up toward the targets and is bare except for a clump of trees splitting the advance lanes.

Quick-fire Range

On this snap-shooting range, a single firer moves along a wooded trail, automatically activating targets (mostly single) and simulators at various angles and distances from his line of approach. Twenty-two targets at angles of 0° to 90° and ranges of 20 to 80 meters are included. Many of the targets are camouflaged and hard to see, although all are actually in view.

Firing at Targets at Successively Closer Ranges

The firing line consists of concrete foxholes above the military crest of a low hill that faces a larger hill with bare, gentle slopes. Groups of four to six targets are exposed on the facing slope at successively

closer ranges, beginning at 480 meters and stopping at 110 meters. Six laterally moving pop-up targets and 60 stationary pop-up targets are included. Four of the target groups have one automatic weapon simulator; the rest have none. Typically, each group raises all its targets once, lowers them, and then raises single targets in random sequence. Thirty-seven of the sixty-six targets are located 180-300 meters from the firing line. Ten firers can fire at the same time.

Night firing is done on this range using a four-foxhole firing line above the day positions and shorter distances to the targets. Forty-nine targets at varying ranges of 300 to 18 meters are used.

Firing at Targets at Longer Ranges

Long-range firing is conducted on the same range as above, using only the most distant day targets, that is, the targets between 300 and 480 meters.

SUITABILITY OF CDEC AND INFANTRY BOARD RANGES FOR EFFECTIVENESS TESTING

As can be inferred from the foregoing descriptions and is apparent in the depictions of the range layouts in Appendix F (Figures F-1 through F-3, F-7, and F-8), neither the CDEC nor the Infantry Board ranges in their present form are suitable for field experiments measuring small arms effectiveness. The lack of appropriate vegetation and concealed targets, the unrealistic deployment of targets, and the absence of realistic target firing cues are the main deficiencies. However, technical deficiencies in the possible interference of shot counters with firers are also important.

It may be possible to modify either range so that limited development testing for effectiveness (see p. II-14) could be conducted. This would be more feasible on the Infantry Board ranges, where adding vegetation for target concealment would not be as incongruous as vegetation introduced on the completely barren ranges at CDEC-HLMR. Using Infantry Board ranges for such testing would also provide the advantages of the Board's more efficient instrumentation. However, extensive changes in firing

positions and target/simulator layout would be required, together with many additional simulators.

ASSESSMENT OF NEW EQUIPMENT AVAILABLE

There is little new equipment that is significantly better than what is in use on the CDEC and Infantry Board ranges. What is available is described in Appendix F and consists mainly of foreign-manufactured pop-up targets. These appear to be satisfactory substitutes for the TRAINFIRE targets that are now out of production. The Marine Corps has procured a sizeable number.

With respect to measuring near misses, the Acubar device* represents the only new equipment (see Appendix F, p. F-36). This device is potentially more rugged and reliable than the microphone systems. A proposed but untested application is the use of an additional set of Acubars well in front of the target to measure the low near misses.

COST OF RANGES FOR FUTURE EFFECTIVENESS TESTING

Costs of the acquisition of the CDEC and Infantry Board ranges are given in Appendix F, as are the probable current costs of operating them. These costs, although illustrative, are not particularly meaningful to those responsible for small arms testing because these ranges would have to be modified before effectiveness-type development tests or full-scale field experiments could be conducted.

Three types of costs are involved in using CDEC or Infantry Board ranges for small arms testing: (1) those of disturbing ongoing programs, (2) those of modifying the range for the particular test, and (3) those of operating the range during the test. The cost of disturbing ongoing programs is difficult to estimate, but a review of the projects conducted

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*Iron bars with piezo-electric transducers attached to each end. The two end-mounted transducers measure the difference in arrival time of initial bar vibrations transmitted down the bar from the point at which the bullet shock first impinges on the iron bar.

on the ranges over the past two years does not reveal any of overriding importance (see Appendix F). Range modification may be expensive. For instance, experiments in only one situation, infantry small arms units assaulting enemy positions, would require extensive modification of either the Infantry Board or CDEC range, probably involving the use of new terrain. Quite apart from the expense, it might be difficult to secure agreement for such modifications. Moreover, mere changes in target layout would not solve the technical difficulties at either range.

Those responsible for small arms effectiveness testing will probably be compelled to consider constructing a new range and acquiring equipment for it. In some ways this presents few problems. Mini-computers and peripheral equipment are available that can perform the control and data recording functions for such a range, at a cost, including software, of $30,000 or less. As is noted in Appendix F, foreign-built pop-up targets are available for about $3500 each; land lines and installation would probably not cost more than $1000 per target.

With respect to the recording of shots fired, should the Infantry Board system prove to interfere with firing, several other feasible approaches apparently exist. Several proposals judged technically adequate but somewhat more expensive were submitted at the time the Infantry Board system was procured.* Some of these involved minimal interference with firer and weapon.

The most difficult technical problem to be faced is the measurement of miss distance for low near misses. If low hit panels in front of the target prove unsatisfactory, it may be necessary to initiate a development program for new measuring devices, although the two-step procurement procedure might be sufficient.

In general, a new small arms range fully instrumented for effectiveness measurement will probably cost about $10,000-$15,000 per target.**

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*The Infantry Board shots-fired system was acquired through a two-step procurement. Technical approaches were invited and evaluated, and then a fixed-price contract was awarded to the lowest qualified bidder.

**The cost of the CDEC-SAWS range was about $15,000 per target.

This includes a weapon simulator for each target, miss distance measurement at each target, and a minimum capacity of ten firers firing simultaneously. The main uncertainty is the cost of miss-distance measurement. Below is the estimated investment cost per target of a new system installed and checked out:

Equipment	Cost per Target
Target mechanism and target bodies	\$ 3,500[a]
Wiring and installation	1,000
Miss-distance measurement	3,000[b]
Target simulator	2,000
Shots-fired counters (\$20,000 ÷ 50)	400
Computer control and recording (\$30,000 + 50)	600
Total per target	\$10,500

[a]Moving target, \$8000.

[b]If adequate, new miss-distance measuring equipment cannot be obtained at this price, it is unlikely to be obtained by spending more money. If so, CDEC or Infantry Board microphone systems can be used as a substitute.

Chapter VI

FINDINGS

This study is primarily concerned with presenting information of use to those engaged in small arms testing. Insights and findings gained from this work are presented in the following sections:

GENERAL OBSERVATIONS

1. The terminology in current DOD directives and Army regulations concerned with testing confuses and obscures the types of small arms testing that need to be conducted, as well as the necessary adversary relationship between user and developer.

2. DOD directives and Army regulations have introduced two kinds of small arms service tests into the user's product acceptance process (OT-I and OT-II). The first comes too early in the development of small arms to permit evaluation of their suitability for Army use. The second does not occur until after significant acceptance decisions have been made, and is thus too late to affect decision-making.

3. Current DOD directives and Army regulations separate the responsibility for planning user tests from their conduct and analysis, prohibiting the user from planning major user-oriented tests. The quality of testing, particularly the more important field experiments, is likely to suffer severely under this constraint. There does not appear to be any justification for this separation of responsibilities.

4. Human factors testing has little potential utility in small arms development because of the difficulty of relating its results to combat.

5. The lack of a procedure for effectiveness testing of small arms early in their development restricts the United States' ability to take full advantage of its small arms inventors and innovators.

6. The lack of adequate comparative operational small arms exploitation testing greatly restricts U.S. designers' access to insights that might be derived from foreign weapon developments.

OPERATIONAL TESTING

1. Operational tests designed to evaluate the relative combat effectiveness of units equipped with alternative small arms systems are not clearly understood, and under current DOD regulations do not evaluate developed equipments that are being considered for adoption.

2. The most appropriate organizational unit for operational testing that can be defined at this time is the rifle and machine gun squad.

3. The combat context for small arms operational testing consists of two elements--the target system and the firing line environment. Adequate operational testing can be conducted only in the context of representative, two-sided tactical unit engagements.

4. Combat target range frequencies indicate that much small arms operational testing is conducted at ranges too long to be relevant to combat. The historical evidence demonstrates that ranges beyond 200 to 300 meters for either rifle or machine guns occur in only a few percent of firings in combat. Historical combat data are adequate to characterize the target system.

5. Combat firing situations cannot be as well characterized. However, data presented in this report (which may be biased, being derived from combat photography) indicate a high incidence of fire in upright, as compared with prone, firing positions. They also indicate that first-round firing occurs very quickly (90 percent of aiming/pointing times in the combat film sample examined are less than 1.5 sec), and there is little time to settle into "comfortable" firing positions, because movement precedes and follows most combat firings.

6. Measures of effectiveness are best defined in terms of the specific objectives of each operational test. However, target hits as a function of time, near misses as a function of time, and the level at which these target effects can be sustained as a function of a fixed system weight limit are always important measures.

7. The instrumentation available for making measurements in support of these measures of effectiveness is adequate, with two exceptions: measuring near misses around targets and measuring shots fired while the firer is moving.

8. The equipment available for simulating the target system is adequate, with the exception of realistic moving targets.

9. The performance of test subjects is conditioned by their prior small arms experience. A firer's prior training on one weapon will require extensive retraining to achieve comparable performance on other weapons--particularly if there are substantial differences in the way the weapons are fired.

10. At present there is no set of selection criteria to insure that test units will fire with uniform proficiency when test subjects are selected from a large population and assigned to test units. This implies that six squads per weapon mix is a marginal sample size; twelve squads per mix is probably required to resolve the differences of interest.

11. The small arms firing range complexes at CDEC-HLMR and Fort Benning are not suitable for the conduct of field experiments. Extensive effort would be necessary to make them suitable.

LETHALITY DATA AND TESTING

1. Detailed casualty surveys covering firing circumstances and representative samples of all KIA as well as WIA are the only valid basis for absolute quantitative predictions of serious casualty production per hit. Only two such surveys (covering only Japanese 6.5-mm bullets) are available from World War II; no adequate ones have been performed since then.

2. Properly controlled animal tests can provide valid relative lethality comparisons of different small arms. Tests conducted since the 1928 Pig Board firings have not had adequate controls, and are invalid.

3. Gelatin block tests are useful only to measure "distance to tumble," a rough indicator of relative lethality for conventional bullets.

4. Current computer models for predicting average incapacitation "scores" (erroneously referred to as incapacitation probabilities) provide relative and absolute lethality comparisons that are inconsistent with combat casualty surveys and animal tests.

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13. ABSTRACT

This study includes (1) a description of the various types of small arms tests, the agencies responsible for ordering, planning, and conducting them, and an assessment of the test management structure, (2) a description of the basic steps in designing, conducting, and analyzing operational tests (field experiments) of small arms, with the 1965-1966 small arms test at CDEC presented as a case study, and (3) an evaluation of the conduct of current small arms testing and the facilities and equipment for it at CDEC-HLMR and USAIB.